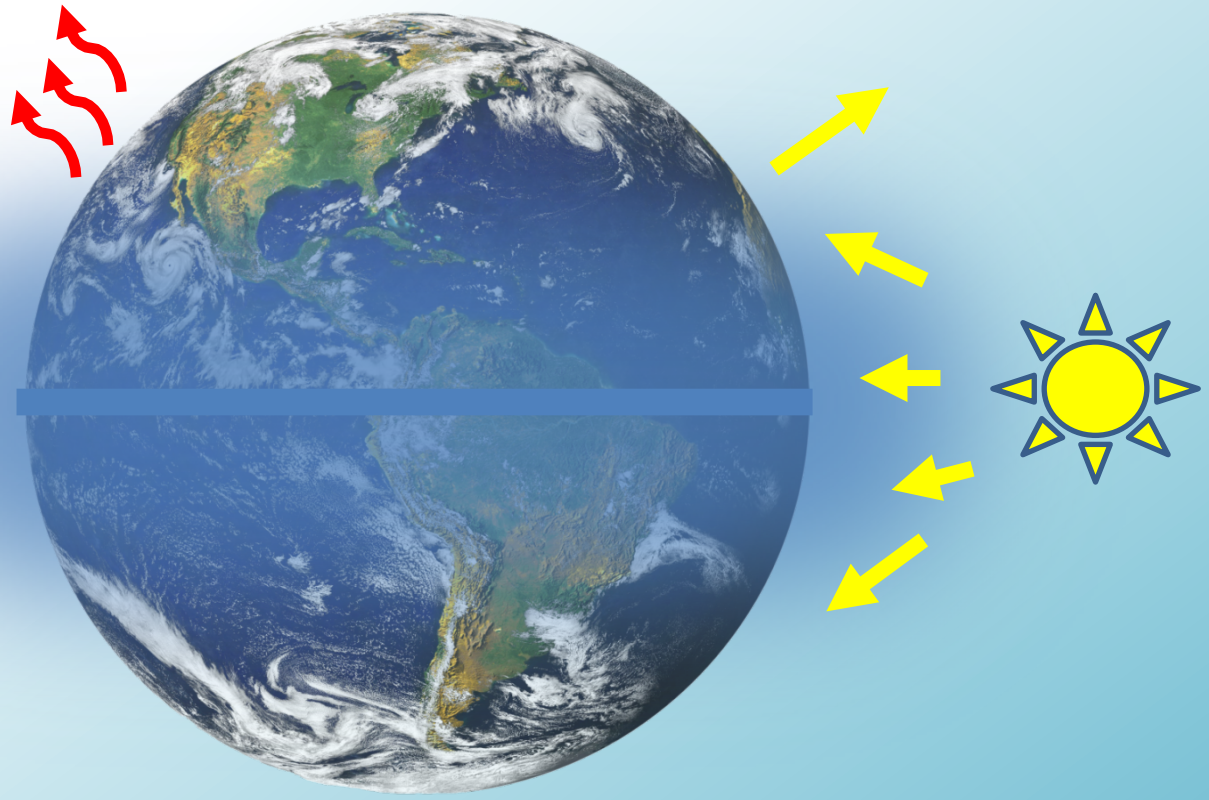
Hemispheric energy balance from an ocean perspective



Maria Z. Hakuba[1,2], Graeme L. Stephens[2,3]

[1] Colorado State University, [2] Jet Propulsion Laboratory
[3] University of Reading

Global Energy Budgets (R Allan, Section Editor)
Current Climate Change Reports
pp 1-13

First online: 26 July 2016

The Curious Nature of the Hemispheric Symmetry of the Earth's Water and Energy Balances

Graeme L. Stephens, Maria Z. Hakuba , Matt Hawcroft, Jim M. Haywood, Ali Behrangi, Jennifer E. Kay, Peter J Webster

10.1007/s40641-016-0043-9

Challenges in energy balance studies

- Large uncertainties in surface energy balance
  - Use of ocean heat data to better constrain
- Regionalization: separation into hemispheres
  - Inter-hemispheric heat transports

Challenges in energy balance studies

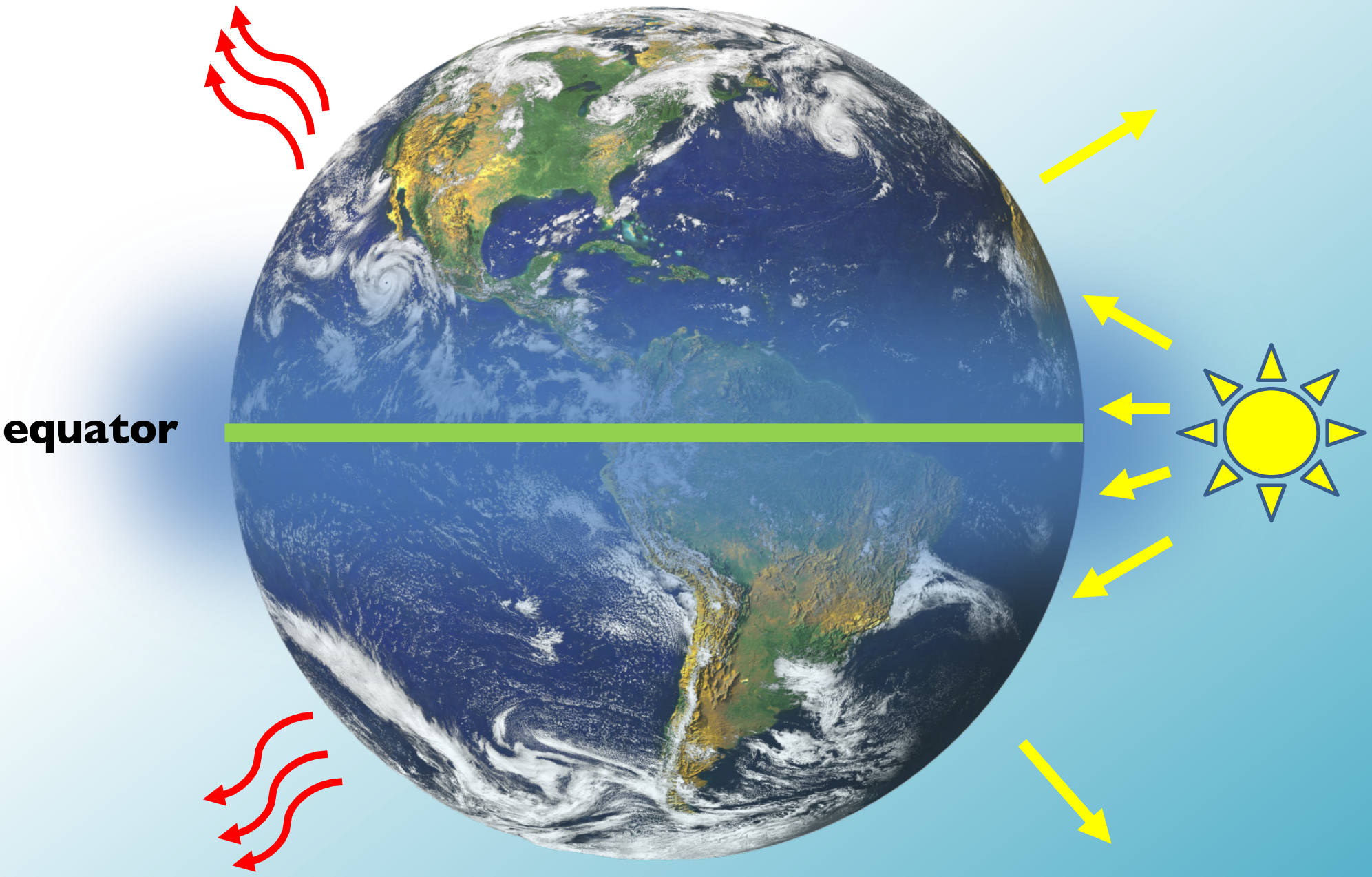
- Large uncertainties in surface energy balance
  - Use of ocean heat data to better constrain
- Regionalization: separation into hemispheres
  - Inter-hemispheric heat transports

GOAL: providing a reference for modeling and atmospheric circulation studies

Global mean energy balance

Net incoming radiation: 0.6 ± 0.4 Wm^{-2}

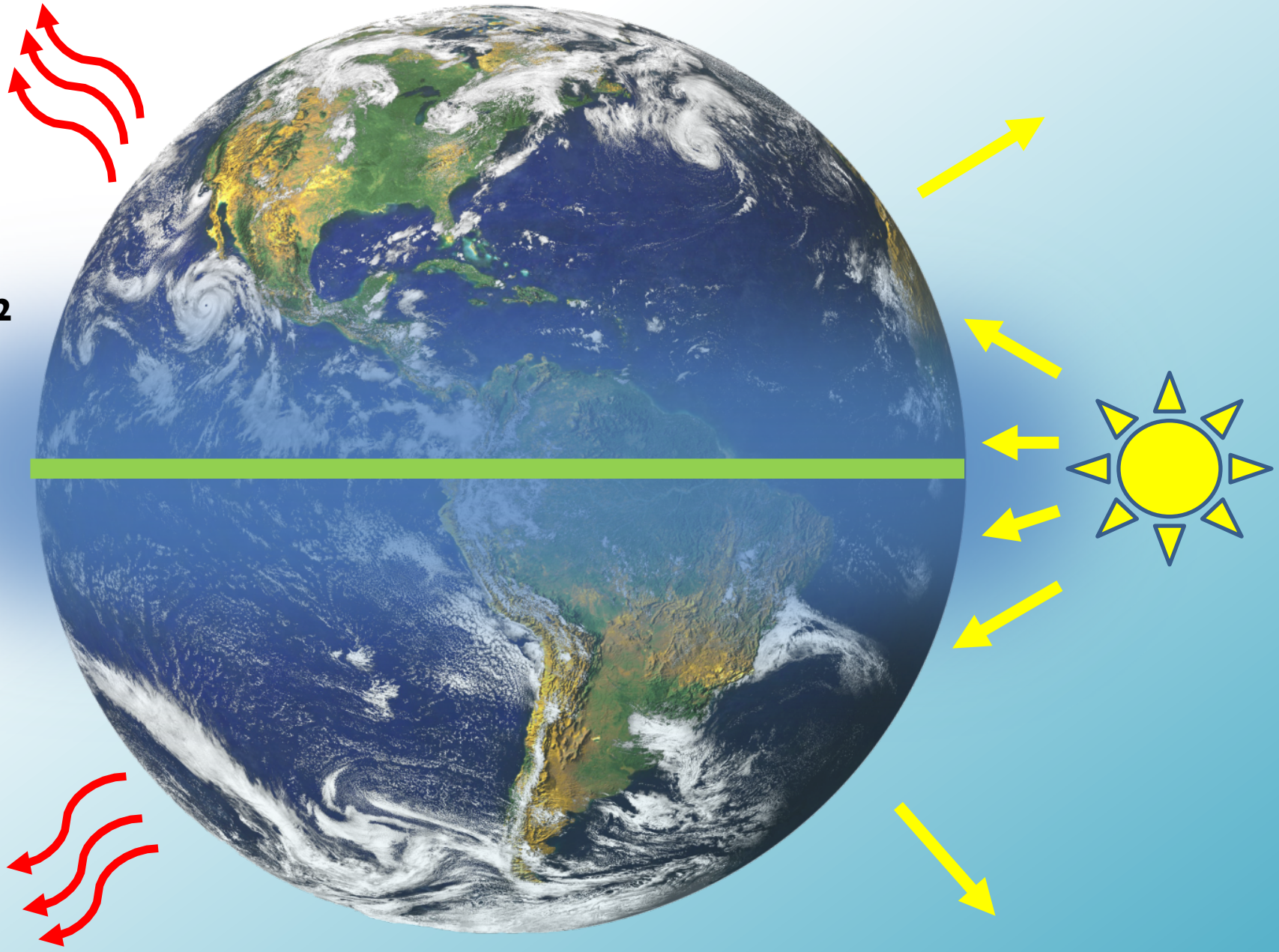
Hemispheric energy balance



Hemispheric energy balance

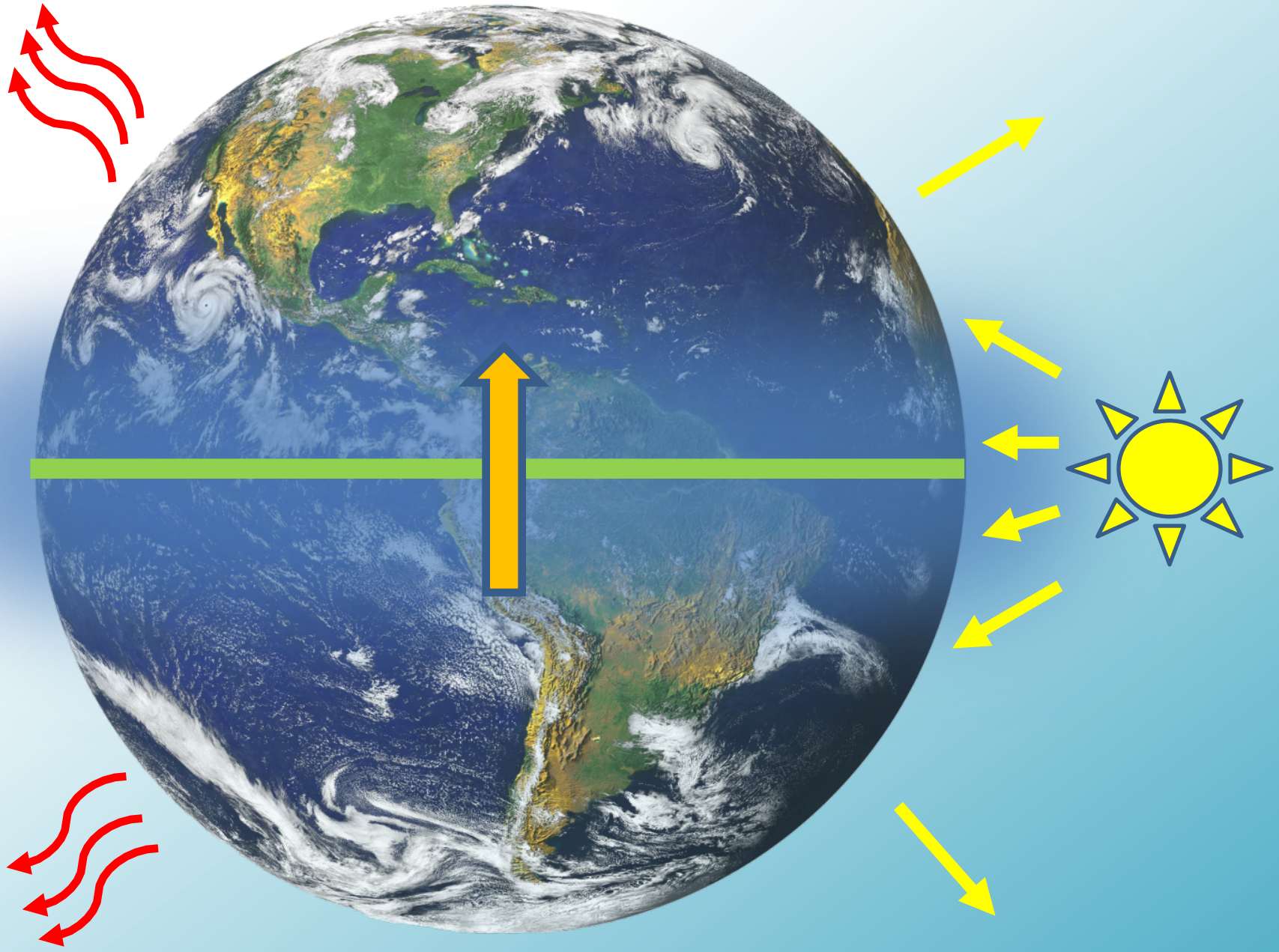
Net incoming radiation: -0.3 Wm^{-2}

Net incoming radiation: 1.5 Wm^{-2}

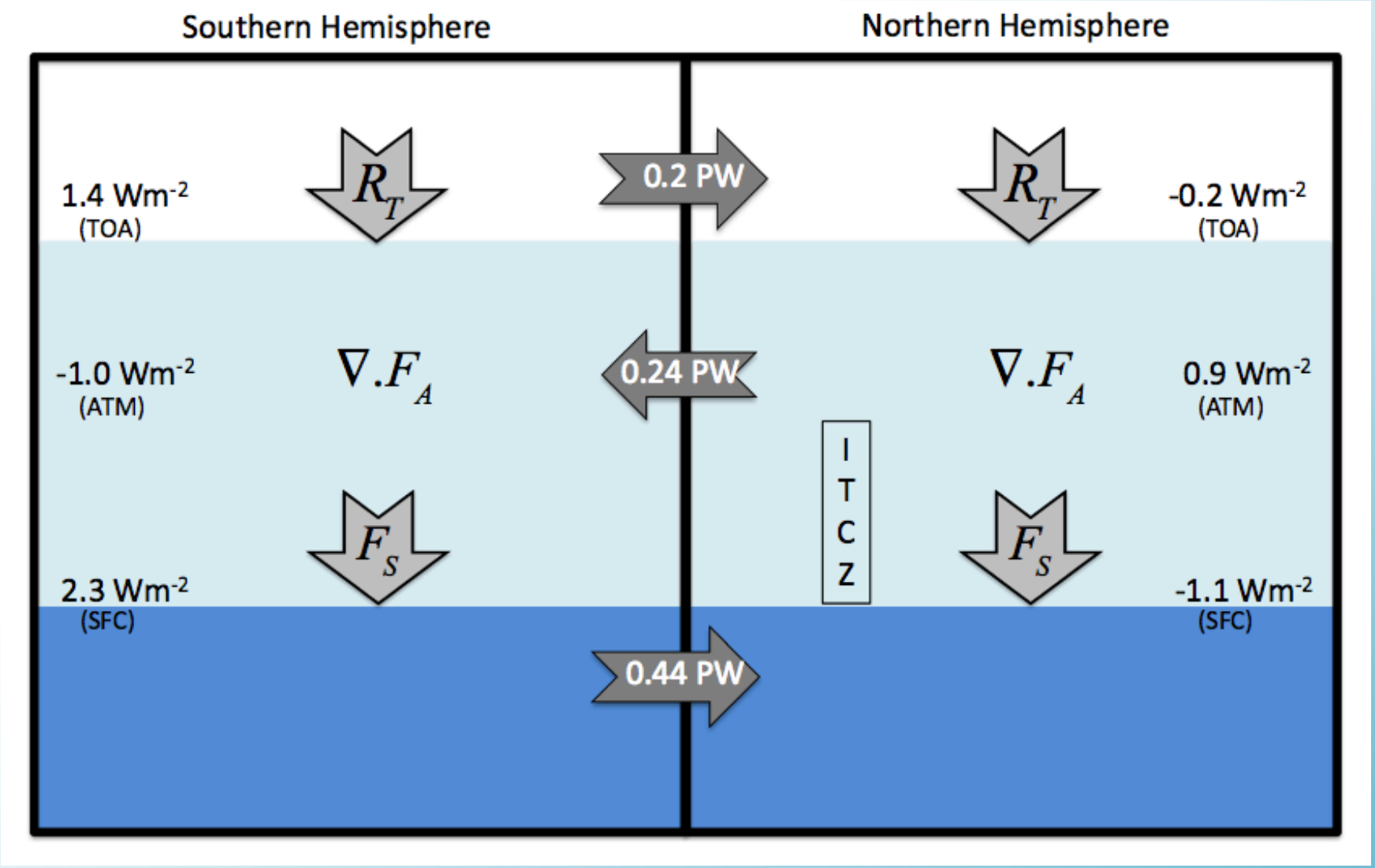


Hemispheric energy balance

Cross-equator energy transport: 0.23 PW

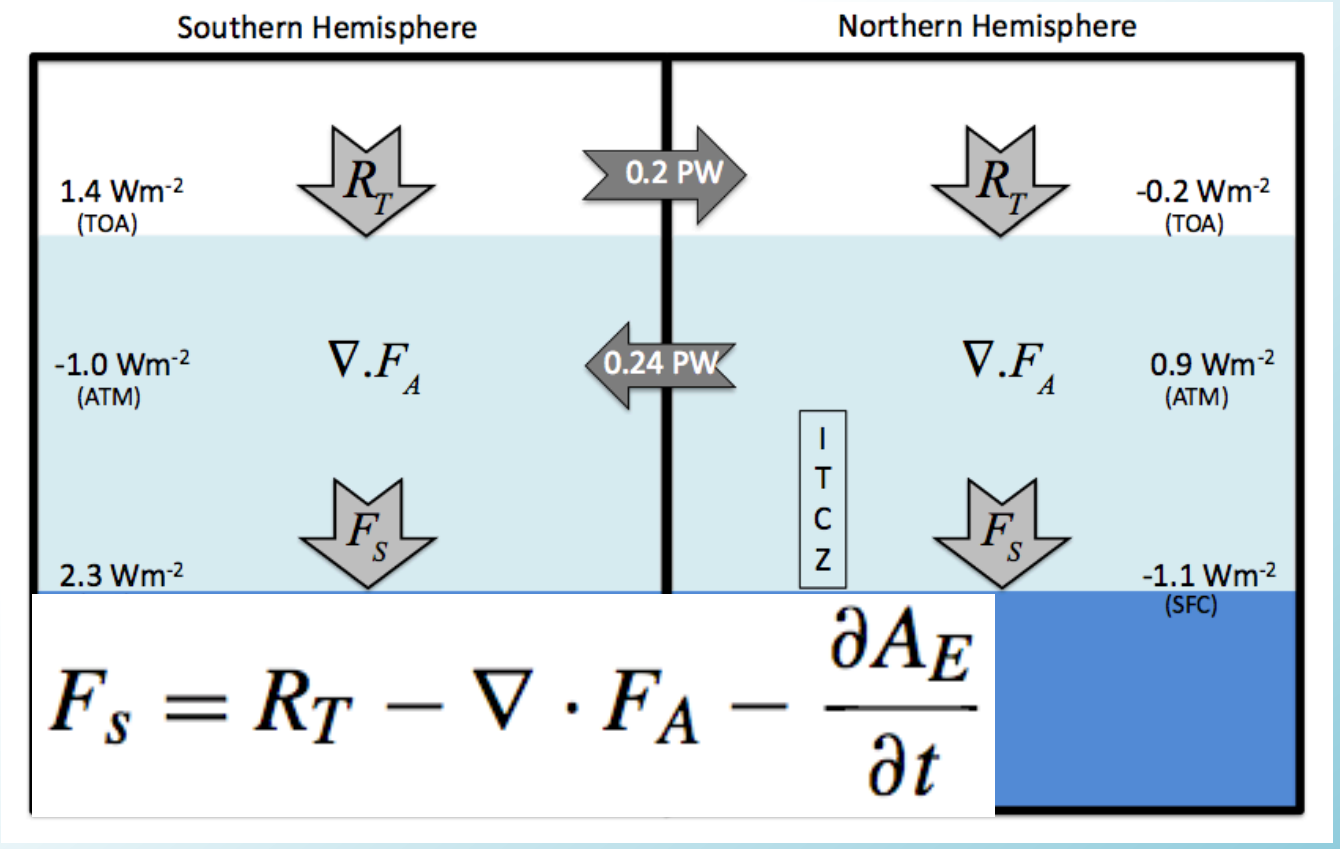


Hemispheric energy balance



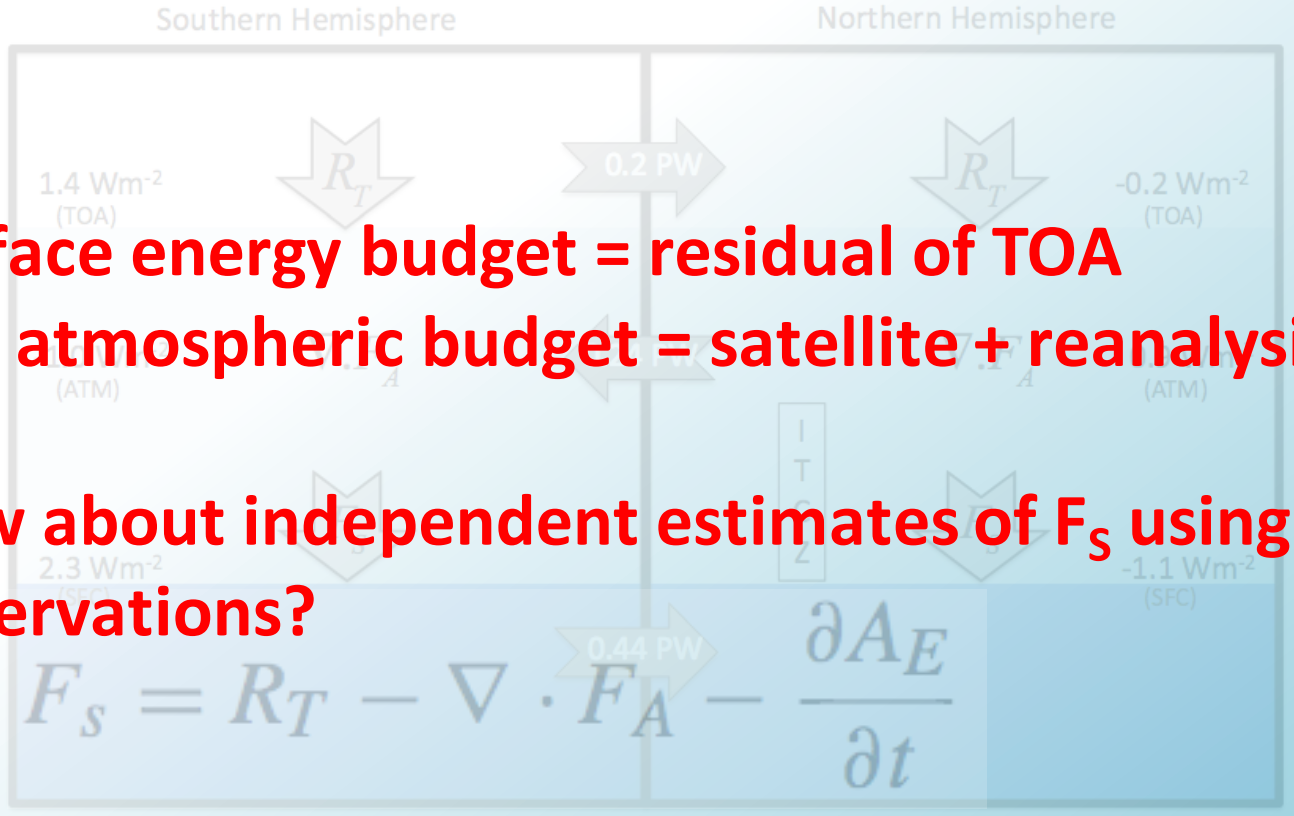
Loeb et al. (2015): Cross-equatorial energy transports from hemispheric asymmetries in TOA, surface, and atmospheric energy budgets

Hemispheric energy balance



surface net heat flux (F_S) inferred as the residual of the net downward TOA radiation (R_T, CERES EBAF) and ERA Interim total atmospheric energy tendency and divergence

Drawback?

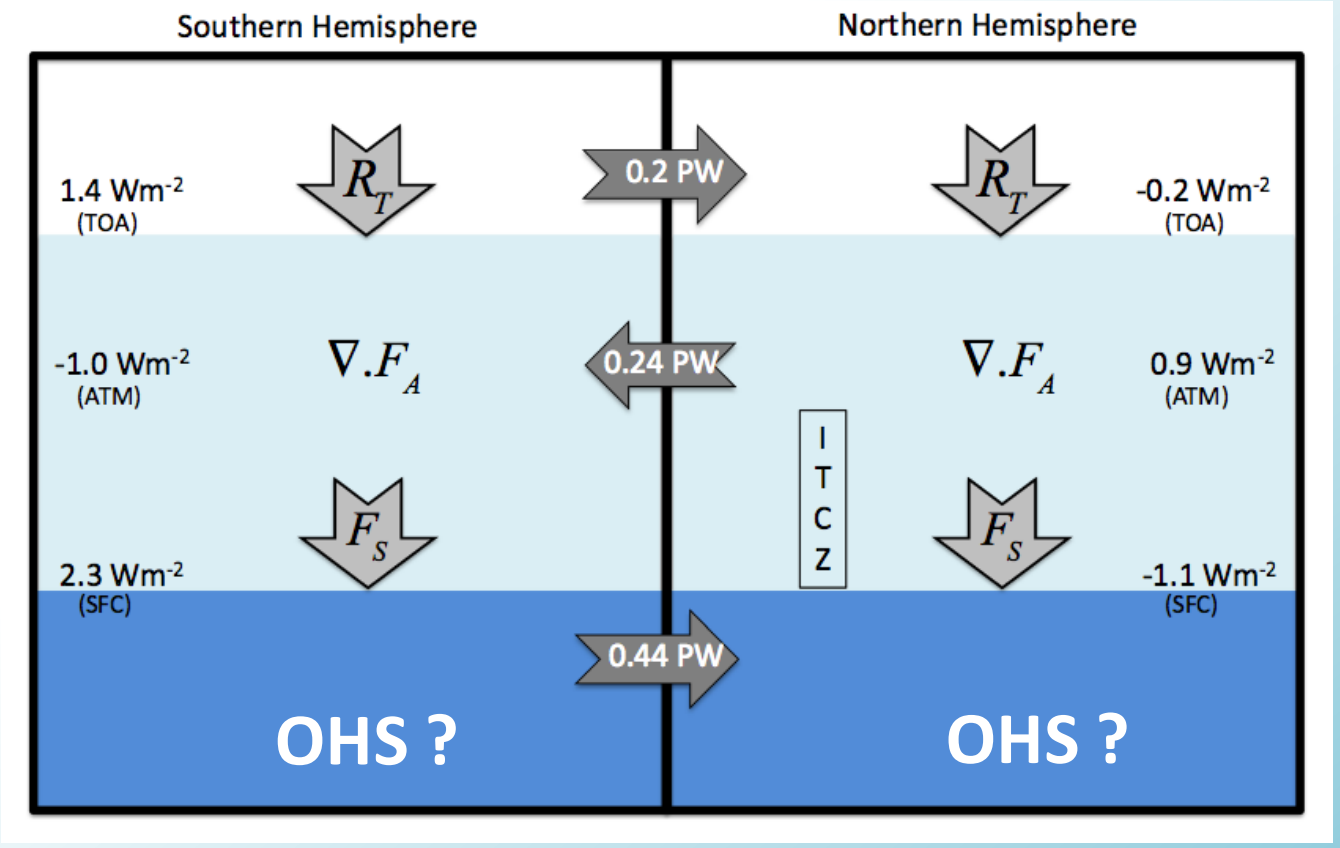


Surface energy budget = residual of TOA and atmospheric budget = satellite + reanalysis.

How about independent estimates of F_S using ocean observations?

surface net heat flux (F_S) inferred as the residual of the net downward TOA radiation (R_T, CERES EBAF) and ERA Interim total atmospheric energy tendency and divergence

Drawback?



Assumption: hemispheric symmetry in ocean heat storage (OHS=0.6 Wm^{-2}).

What if OHS is not symmetric?

Approach

Novel approach to establish hemispheric energy balance from ocean perspective

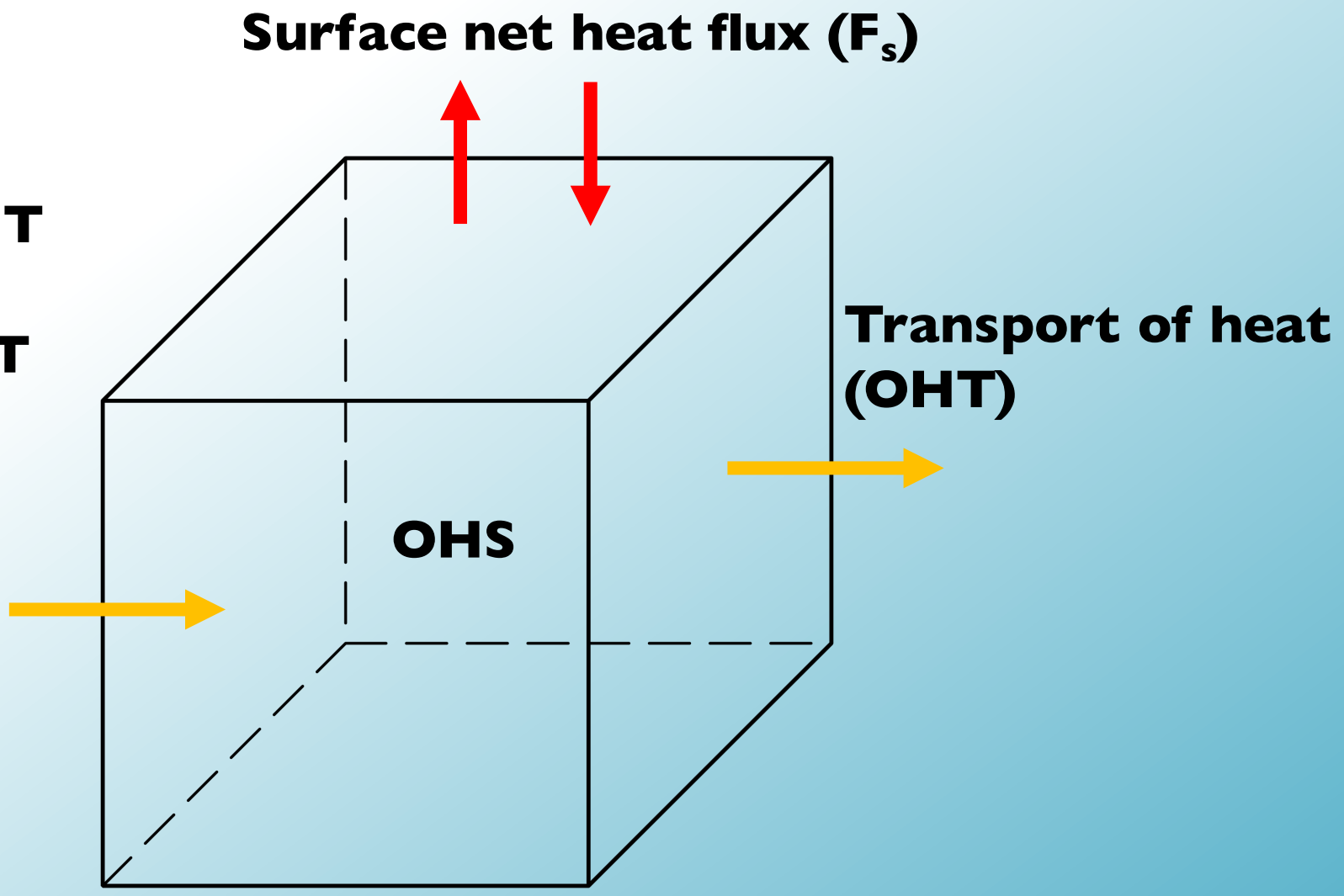
Estimate F_s from directly measured hemispheric Ocean heat storage and "ocean modeled" heat transport

$$\mathbf{F_s = OHS - OHT}$$

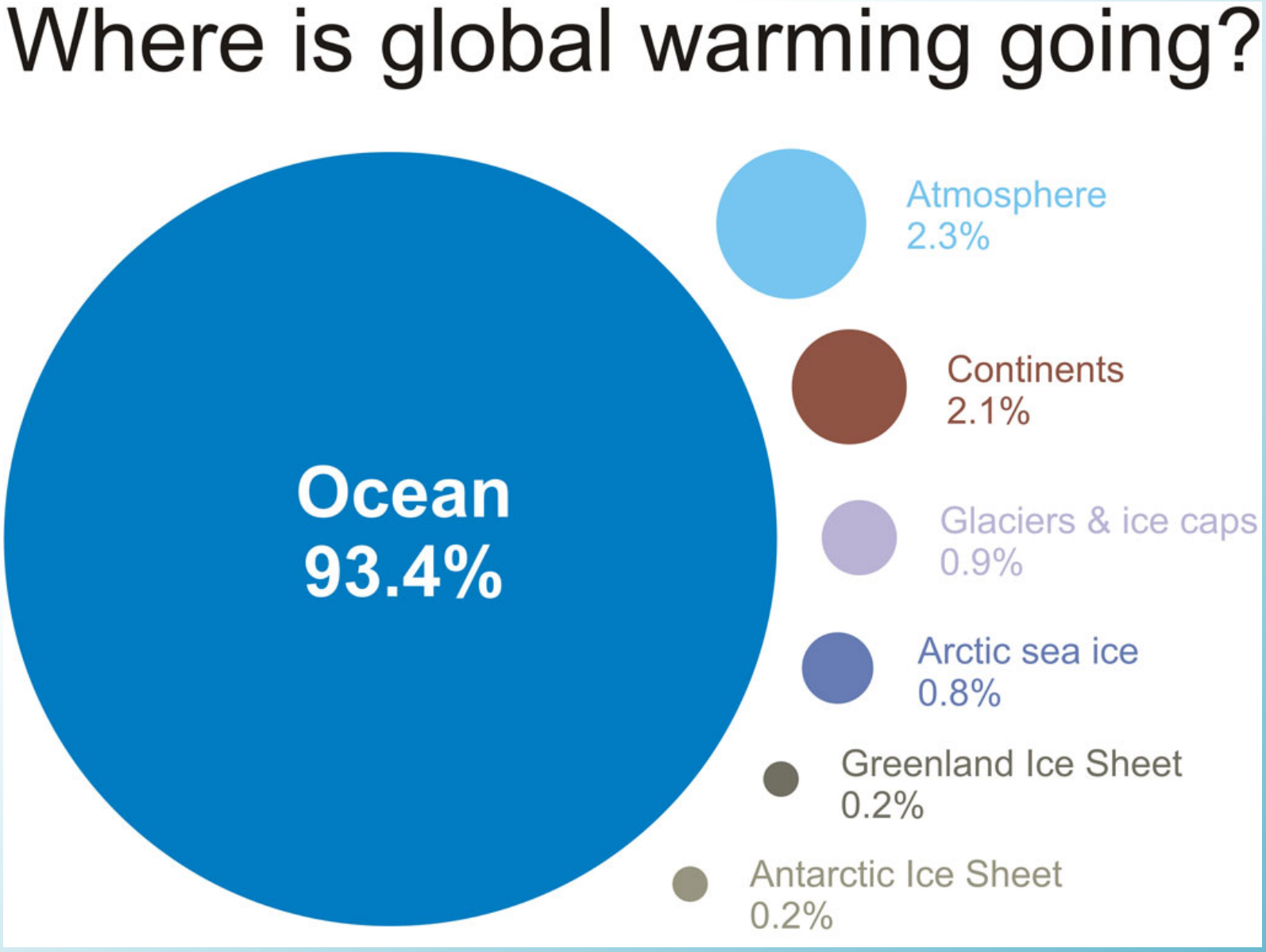
Ocean heat storage OHS

OHS=F_s+OHT

F_s=OHS-OHT



Where is global warming going?

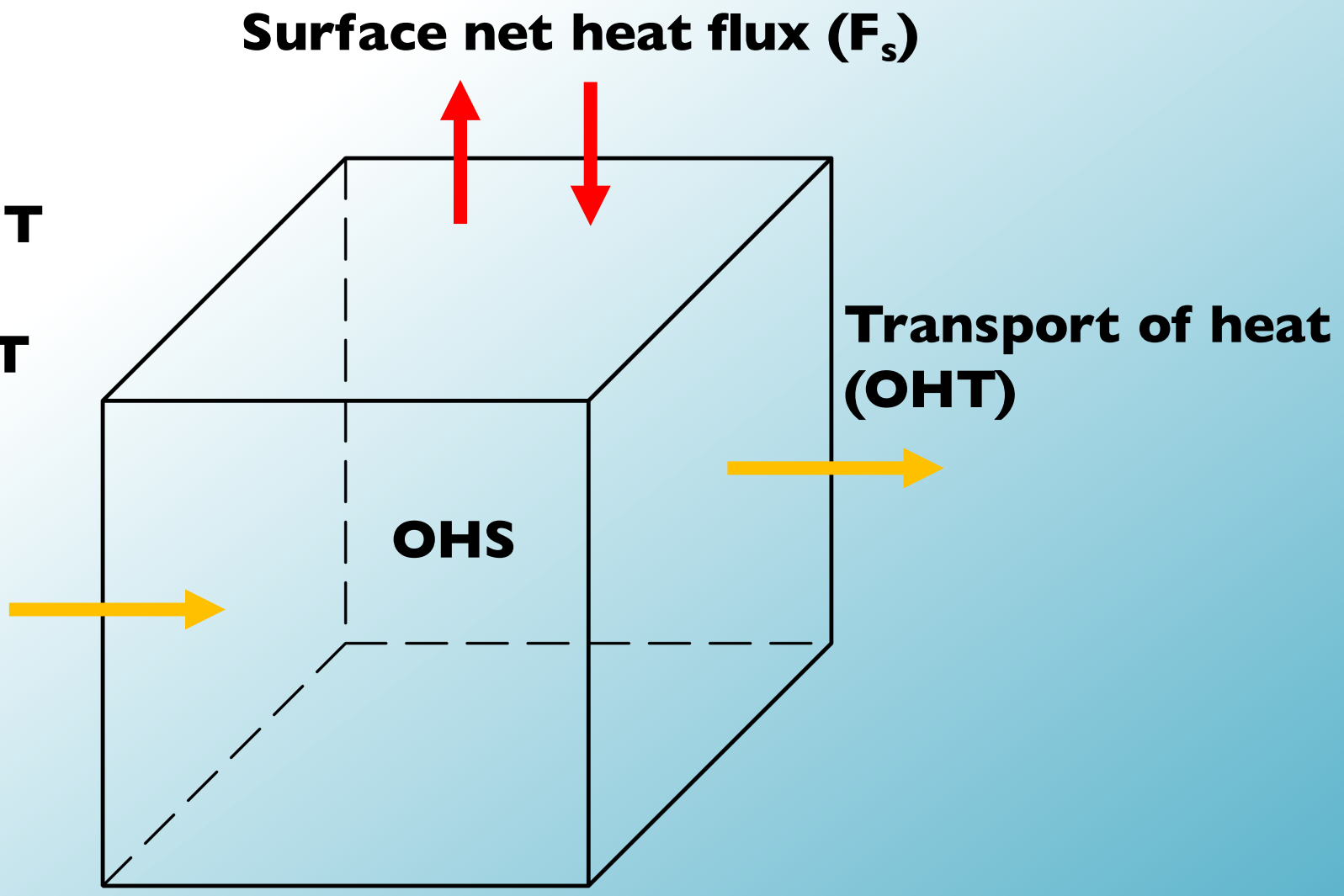


IPCC AR4 5.2.2.3.

Ocean heat storage OHS

OHS=F_s+OHT

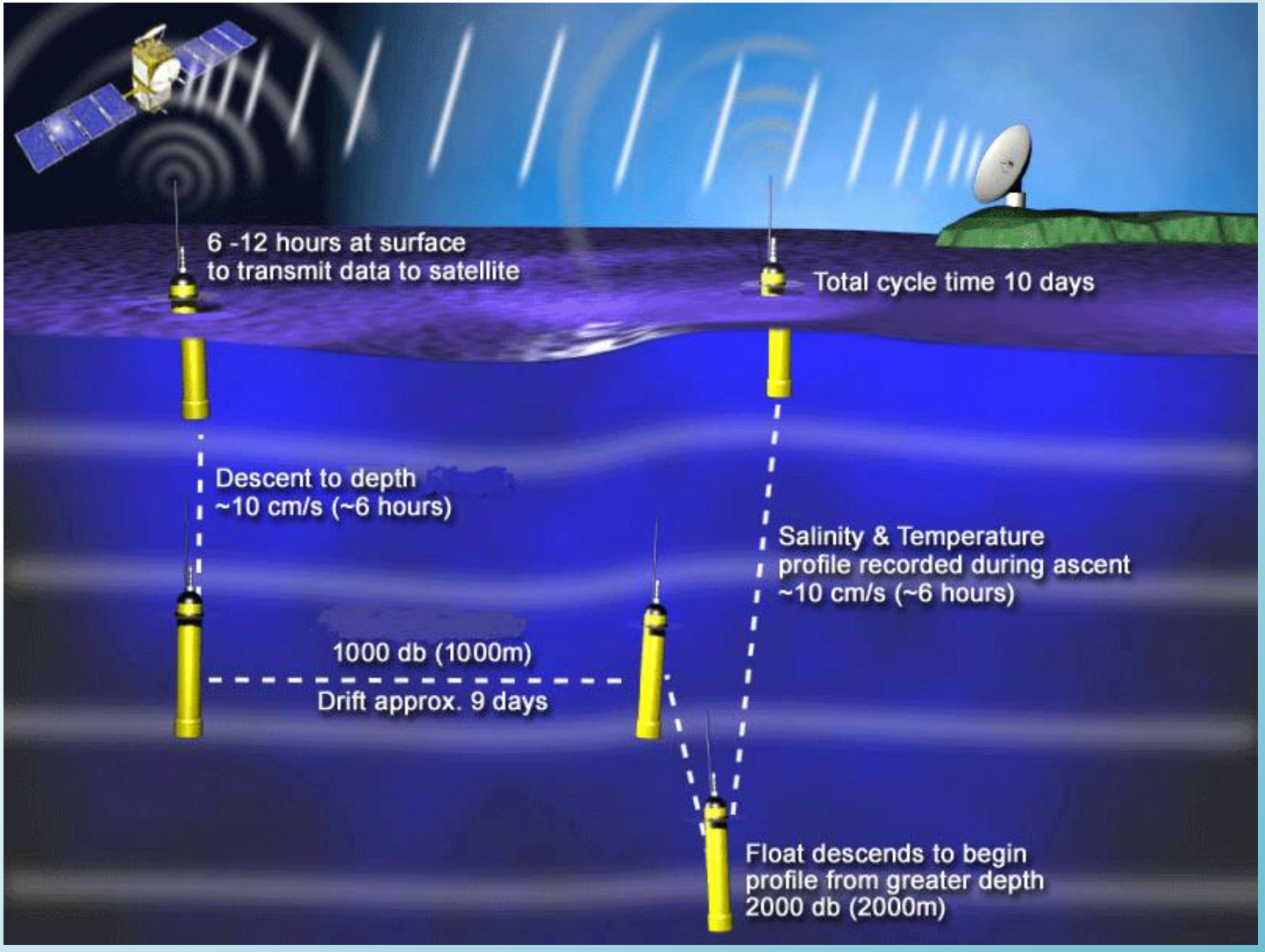
F_s=OHS-OHT



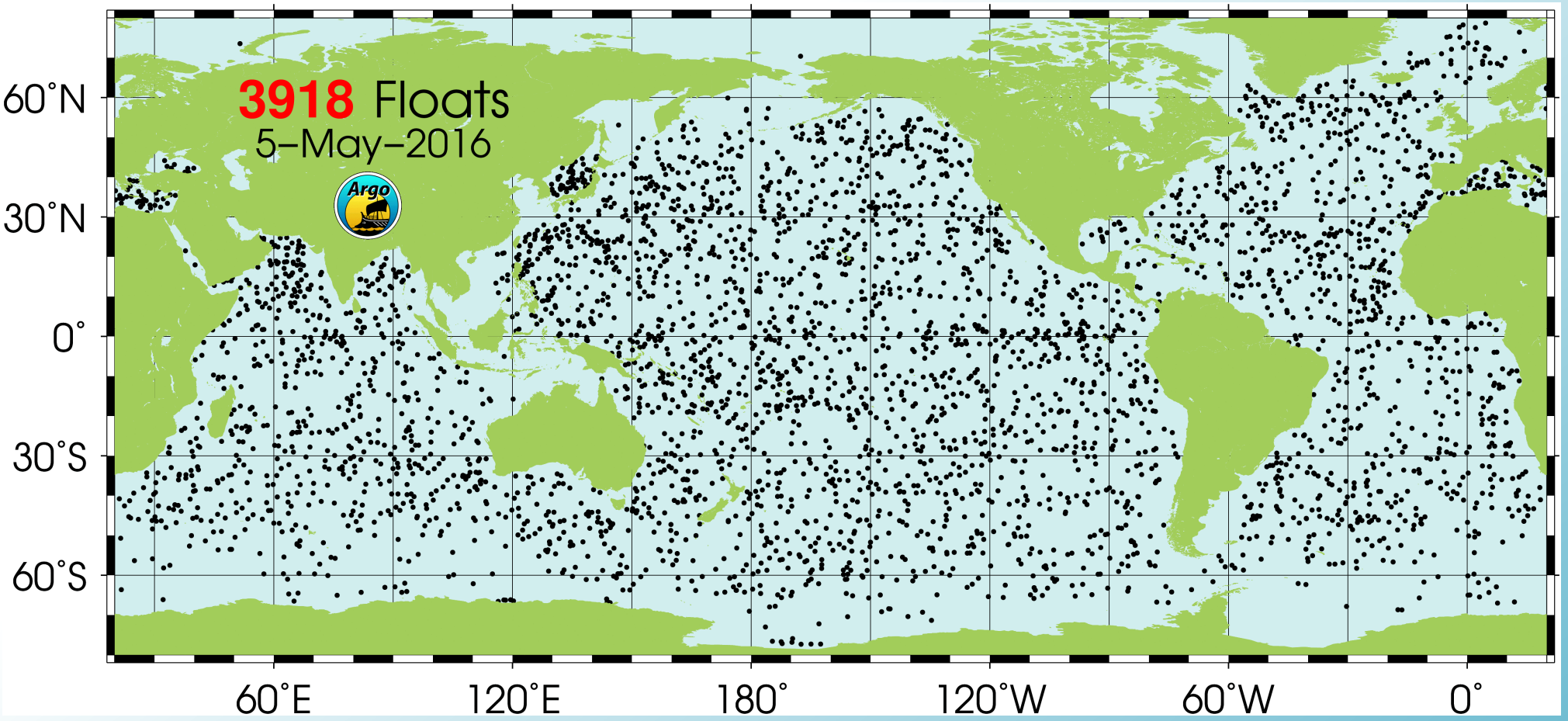
Ocean heat content from in-situ data

ARGO ocean profiling

ARGO ocean profiling



Ocean heat content from in-situ data



Almost 4000 ARGO floats profiling ocean temperature and salinity since 2005

Gridded temperature and OHC (2005-2015)

NOAA (Levitus et al., 2012): ocean heat content from objectively analyzed Argo and other in-situ data
IPRC: variational interpolation from Argo only profiles
Scripps: optimal interpolation from Argo only profiles

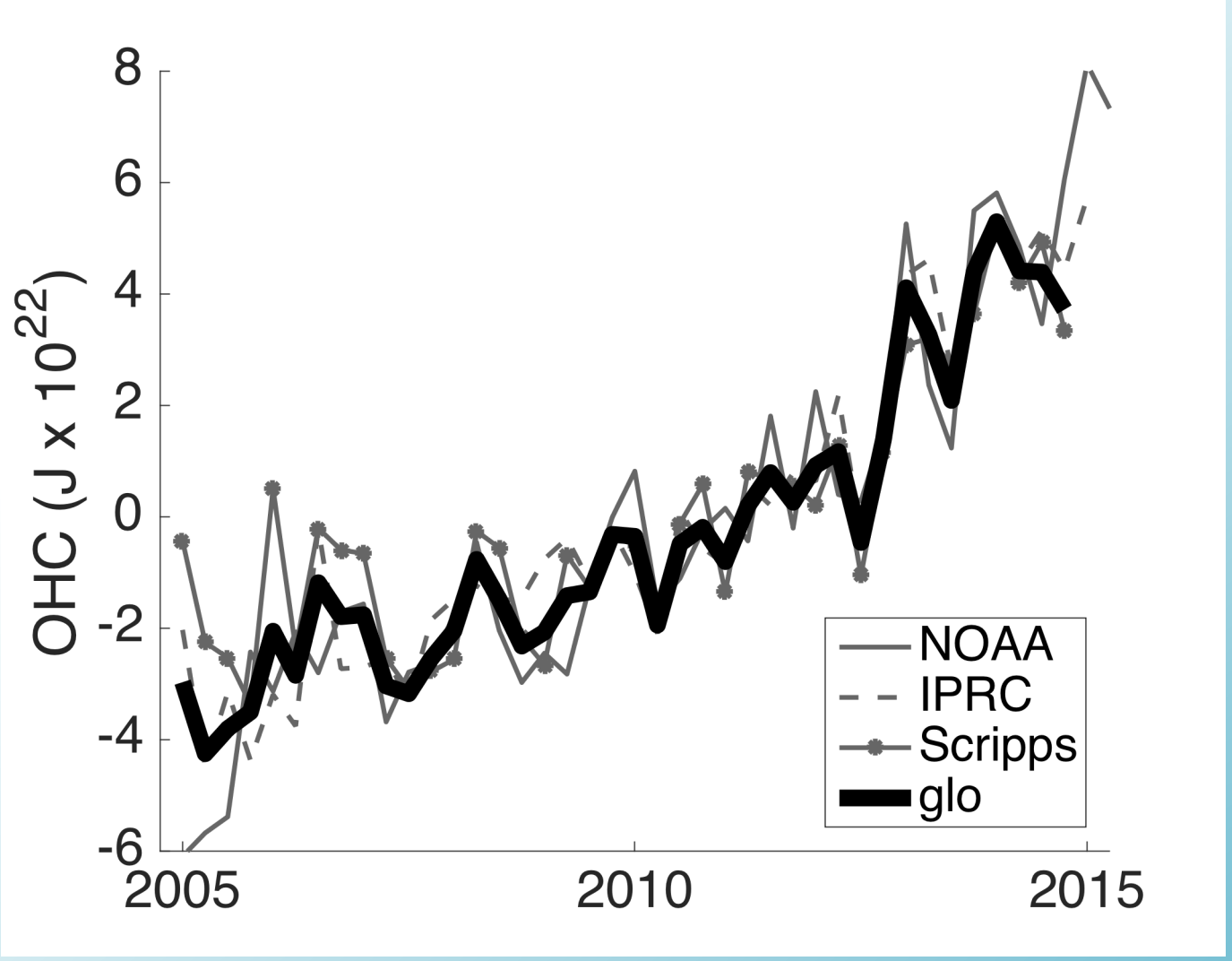
Vertically integrate temperature profiles to compute total heat content in ocean column (Joules) down to 2000m

$$O_E = \int T(z)\rho C_w \, dz,$$

Ocean heat storage/uptake = rate of change in OHC (Wm^{-2})

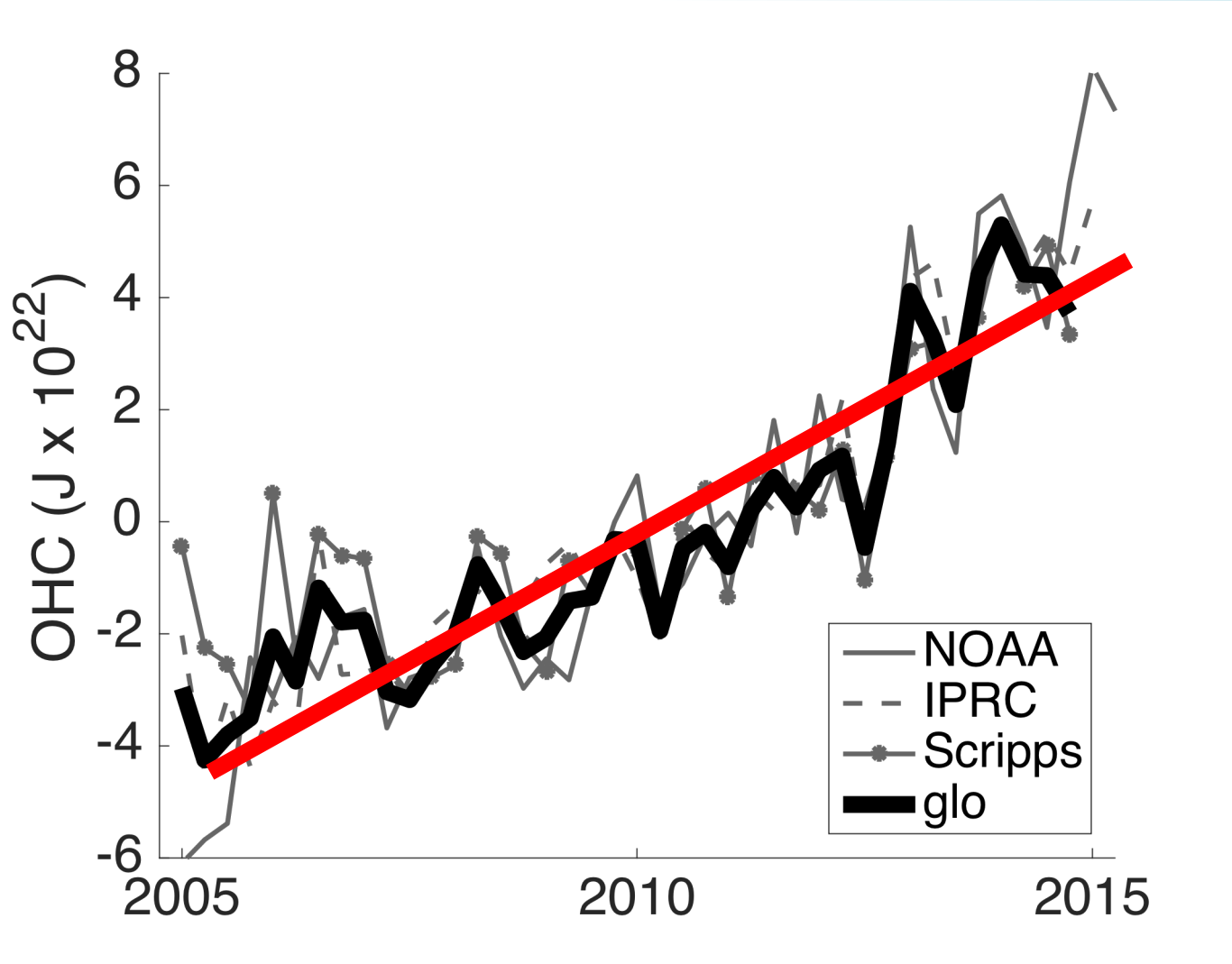
$$\partial O_E / \partial t$$

Ocean heat content global



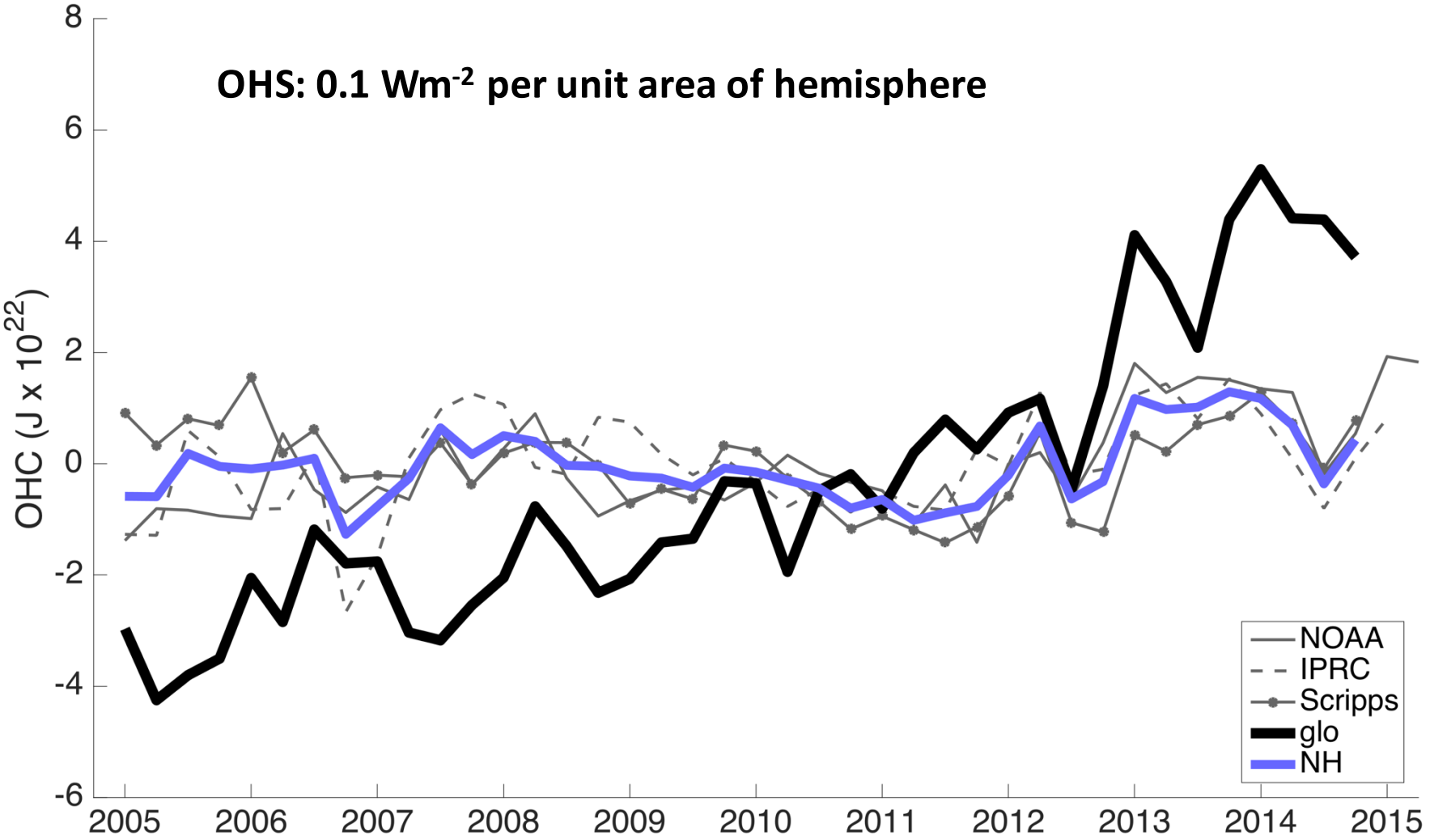
Seasonal anomalies, long-term mean subtracted

Ocean heat content global

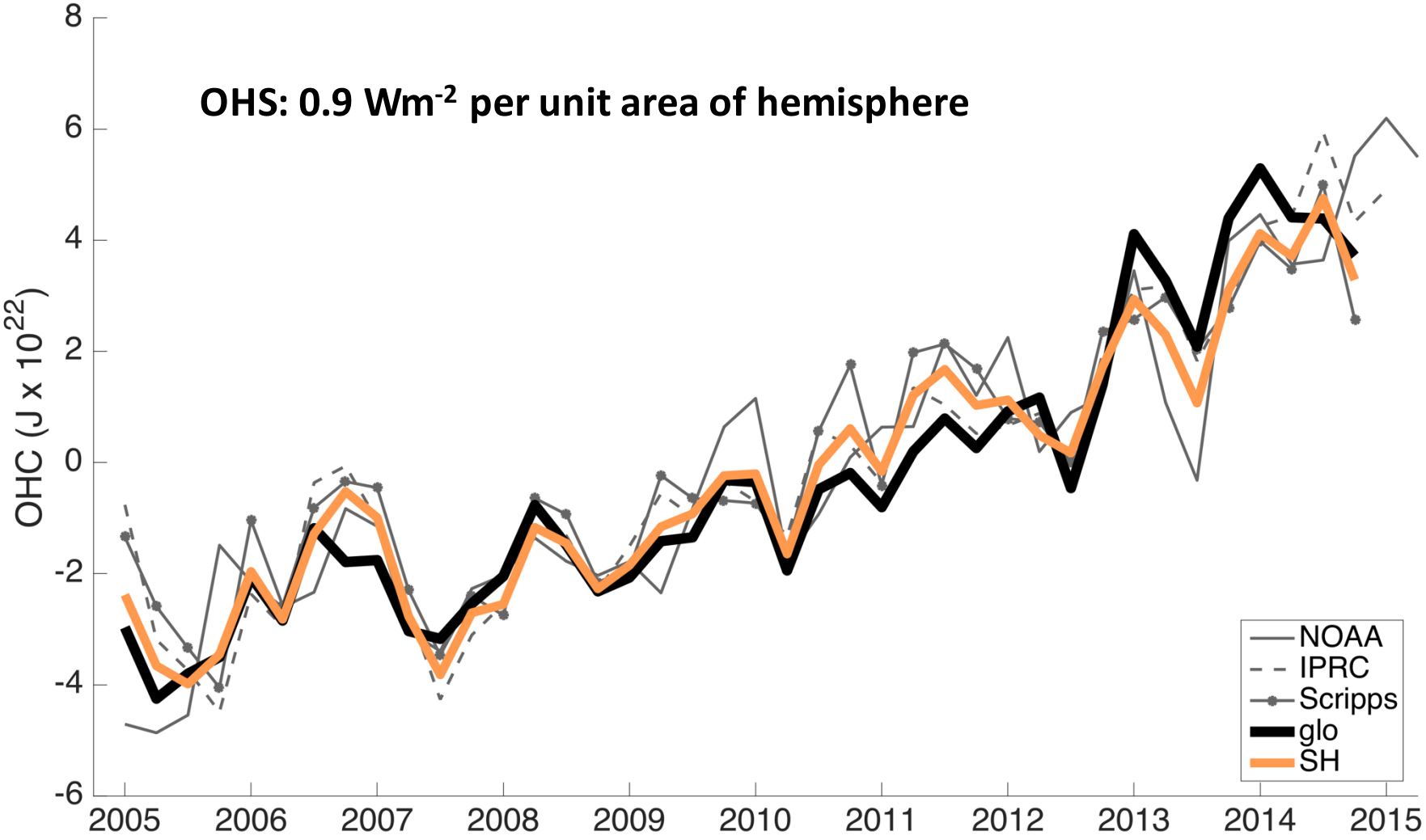


Ocean heat storage: 0.5 Wm^{-2} per unit area of globe

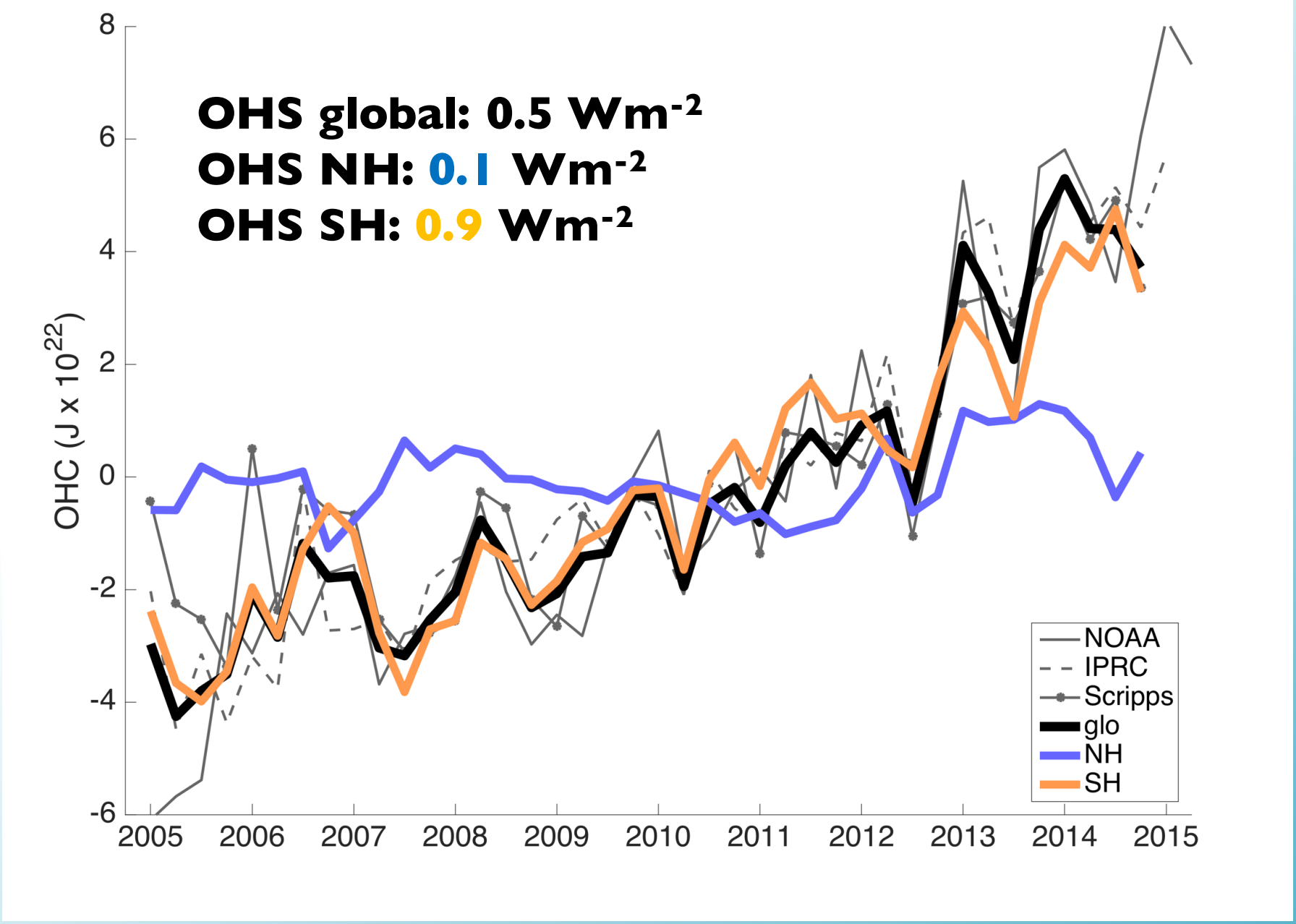
Ocean heat content NH



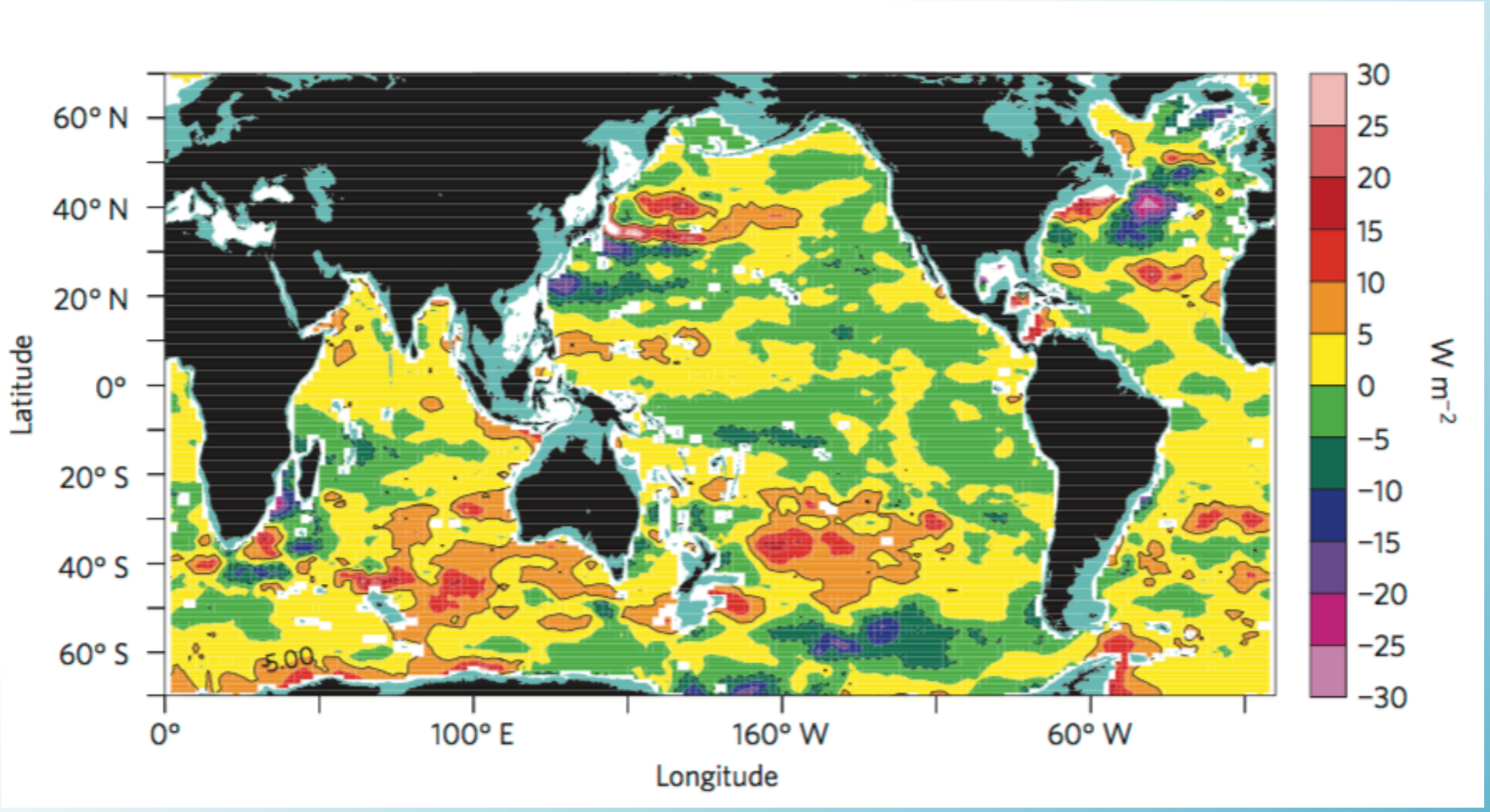
Ocean heat content SH



90% of heat storage occurs in SH oceans



Where did heat go?



Roemmich et al. (2015): most heat gain in Southern extra-tropical oceans south of 20°S: Ekman pumping in subtropical gyres

Challenges with OHS

- measurement errors
- coverage *bias*, marginal and shallow seas (little effect on decadal trends), Arctic and Southern oceans
- deep ocean (> 2000 m) significant multi decadal warming contributes 0.1 Wm^{-2} (Purkey & Johnson, 2010), especially in Southern oceans

- include Deep ARGO, reanalysis and models

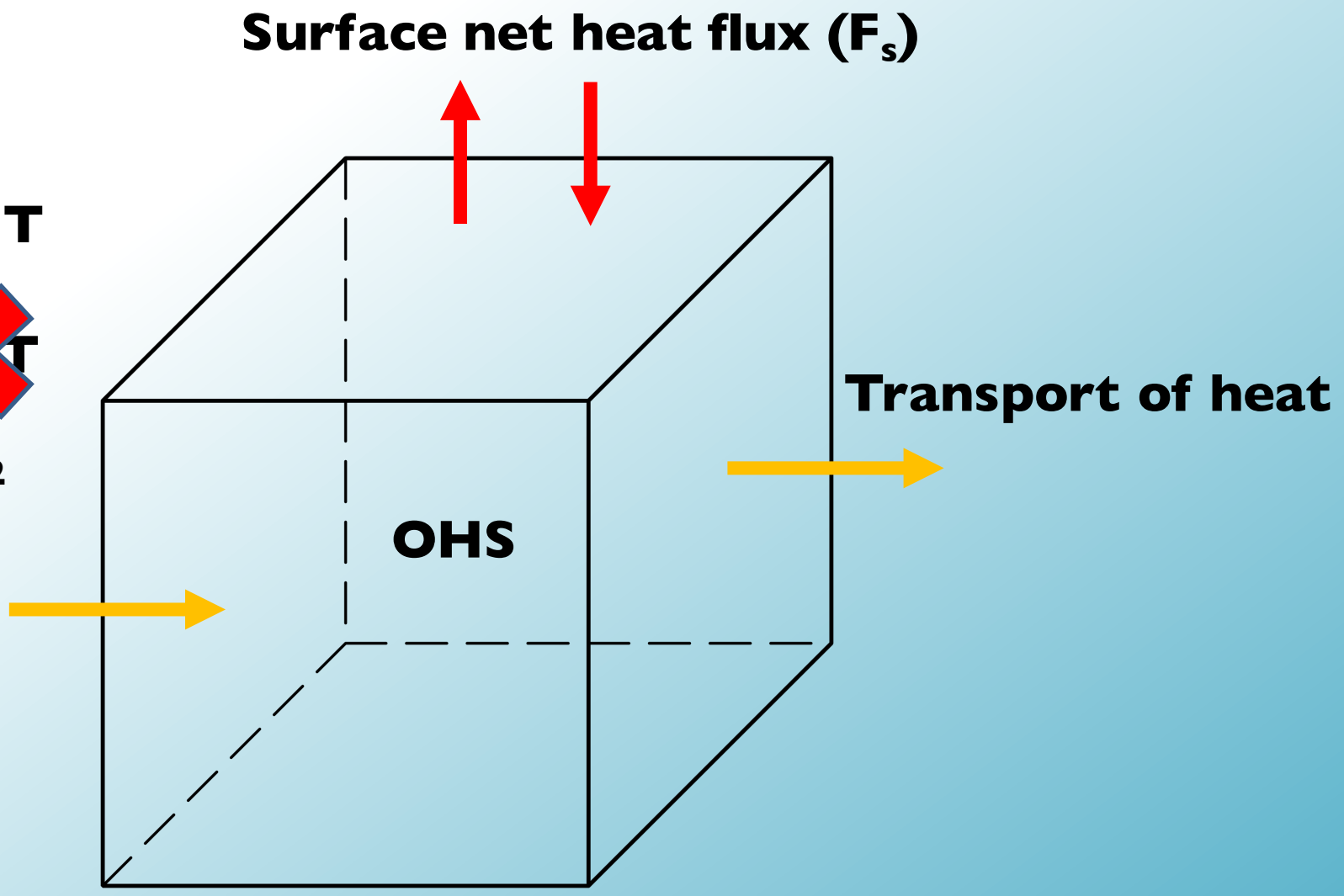
⟶ more datasets more robust statistics?

Surface net heat flux GLOBAL MEAN

OHS=F_s+OHT

Fs=OHS-OHT

Fs=0.5 Wm^{-2}



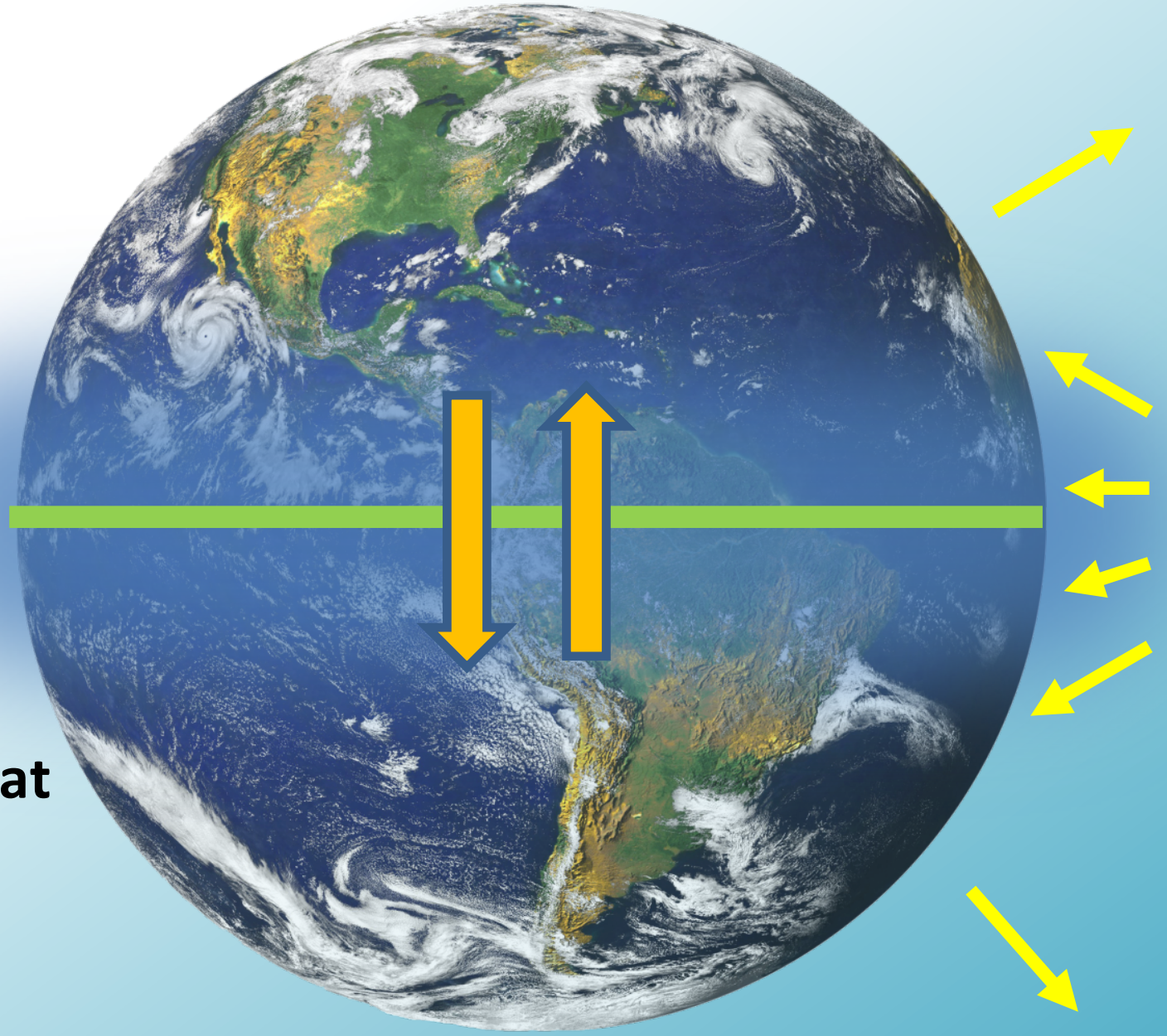
Surface net heat flux Hemispheric MEAN

OHS=F_s+OHT

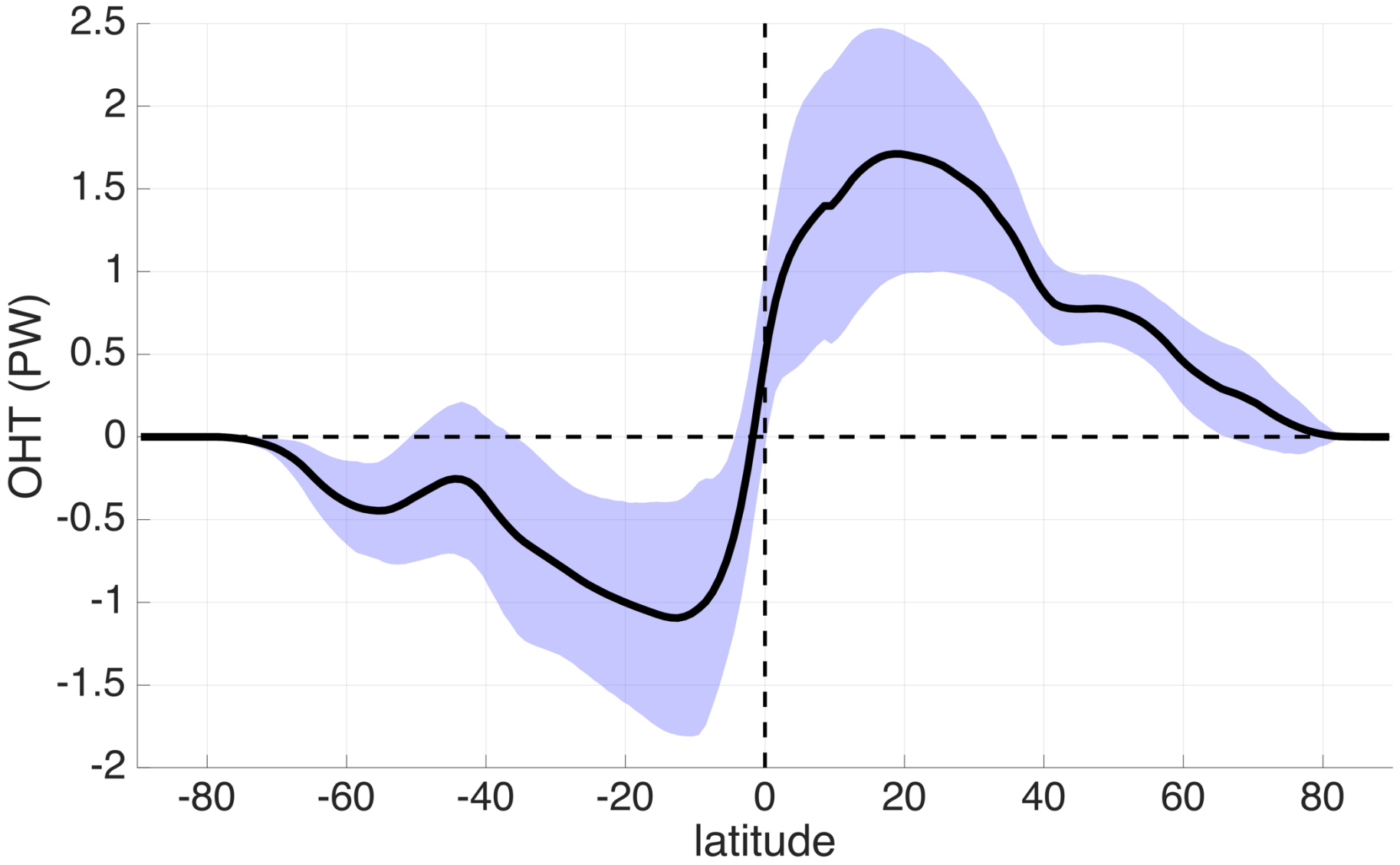
Fs=OHS-OHT

Fs=? Wm^{-2}

Cross-equatorial heat transport?



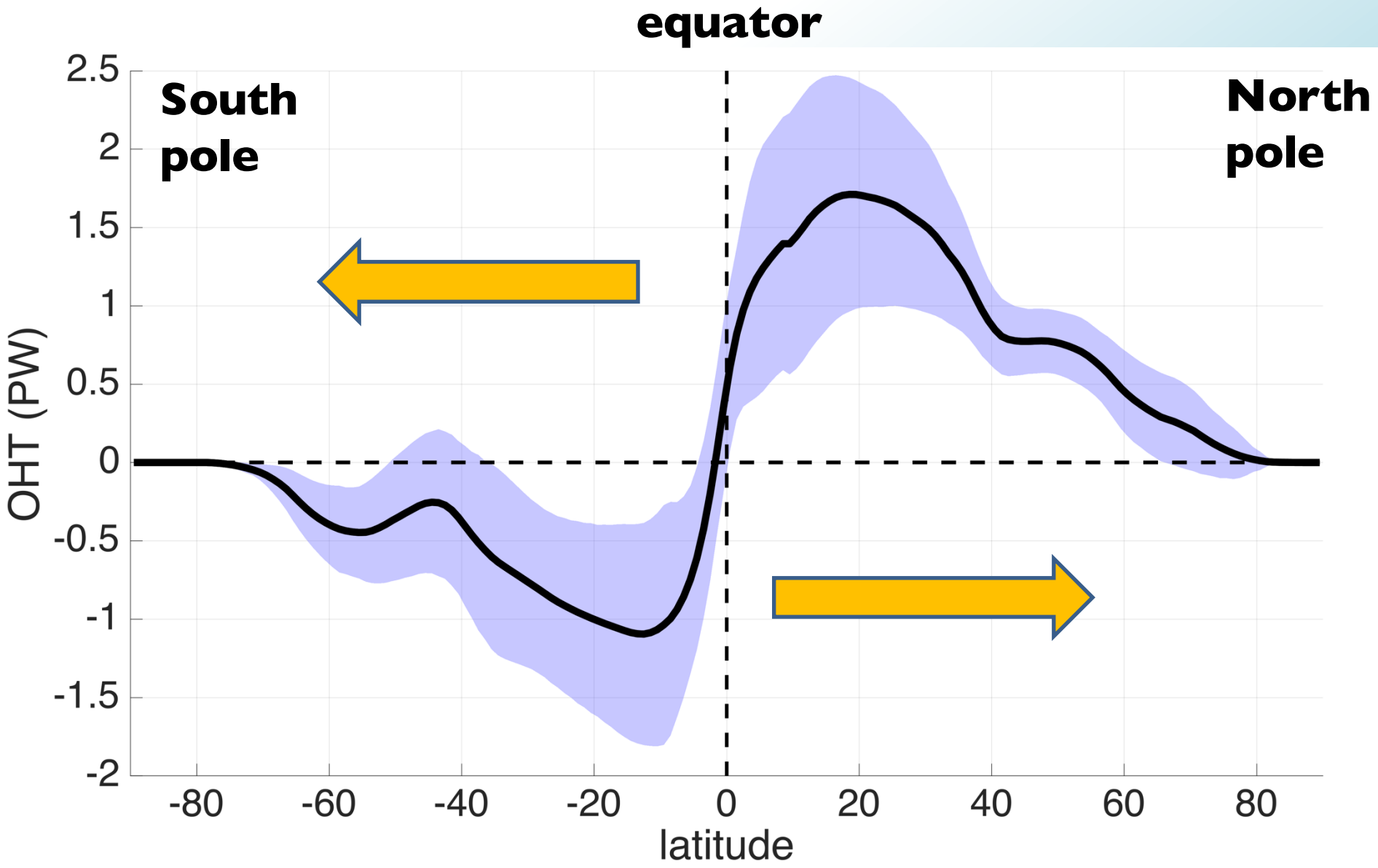
Meridional ocean heat transport



ECCO consortium, combines model with observations to describe ocean state

(ECCO=Estimation of the Circulation and Climate of the Ocean)

Meridional ocean heat transport



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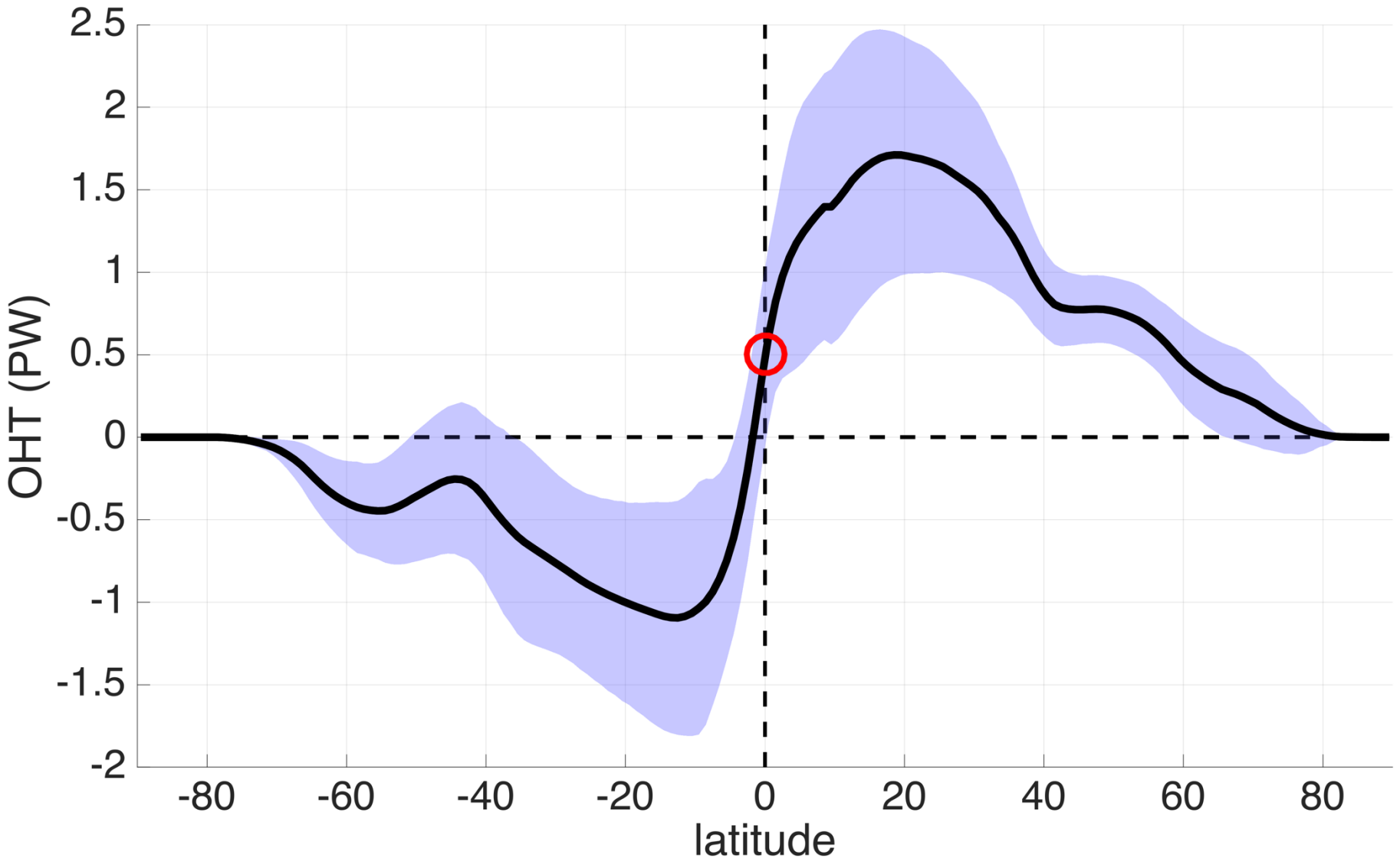
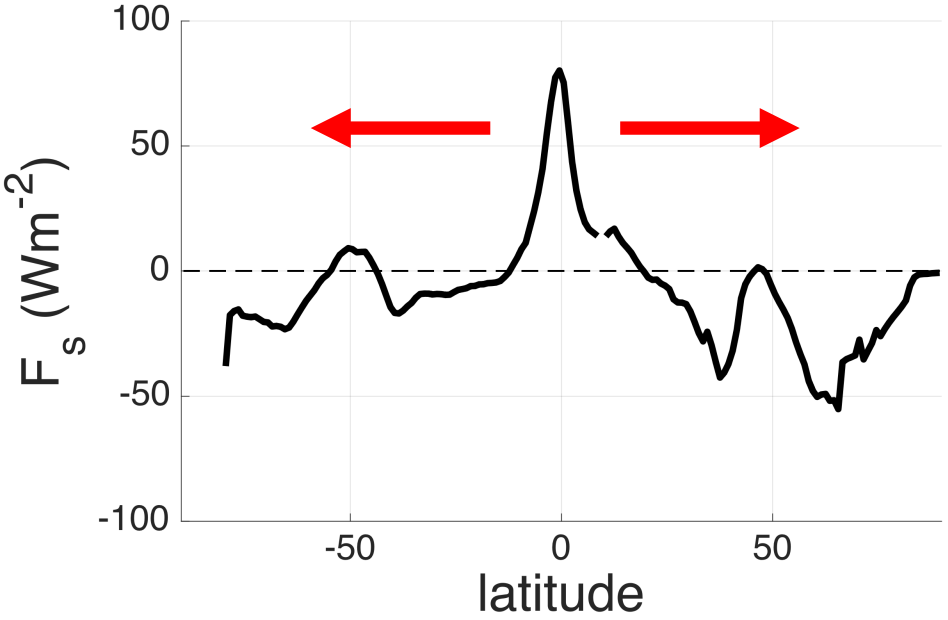


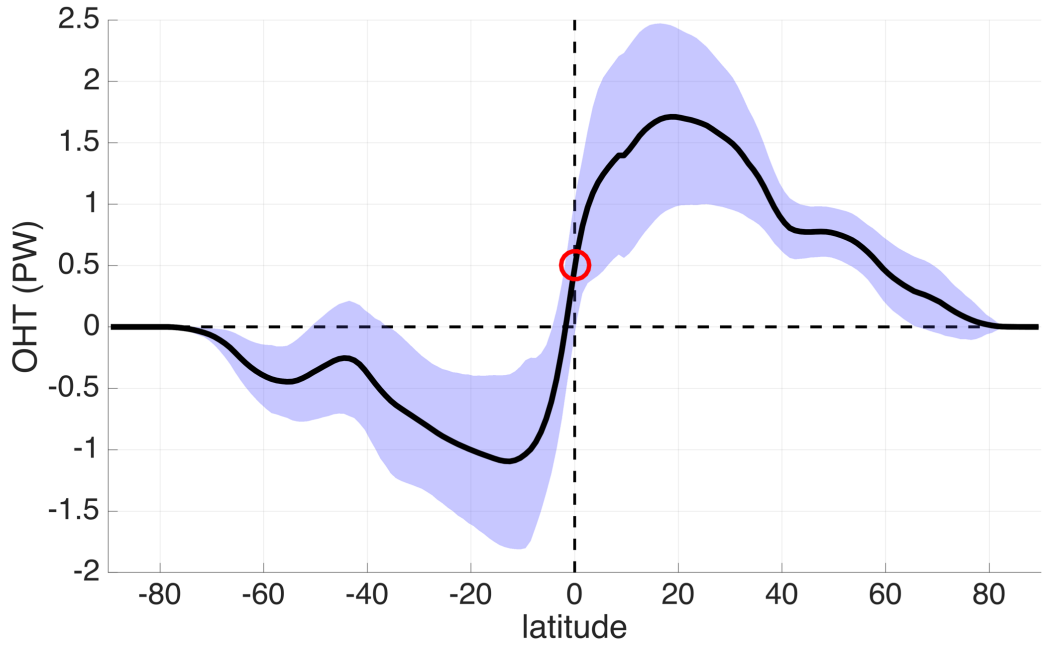
Best estimate cross-equatorial OHT: 0.45 PW

Meridional ocean heat transport

Direct method: $$T_{oc} = \int\int_{wall} \rho\, c_0\, vT\, dx\, dz.$$

Indirect method (for now) zonally integrate sea surface F_s = div (OHT) in annual mean





Surface heat flux Data

- **Estimating the Circulation & Climate of the Ocean (ECCO)**
  Goal is to combine GCM with diverse observations to quantify the time-evolving global ocean state:

  - ECCO-V4 (JPL/AER/MIT) & GECCO2 (UH) use MITgcm

- **Other Reanalysis** (ORA IP, Balmaseda et al. 2015, Valdivieso et al. 2015):

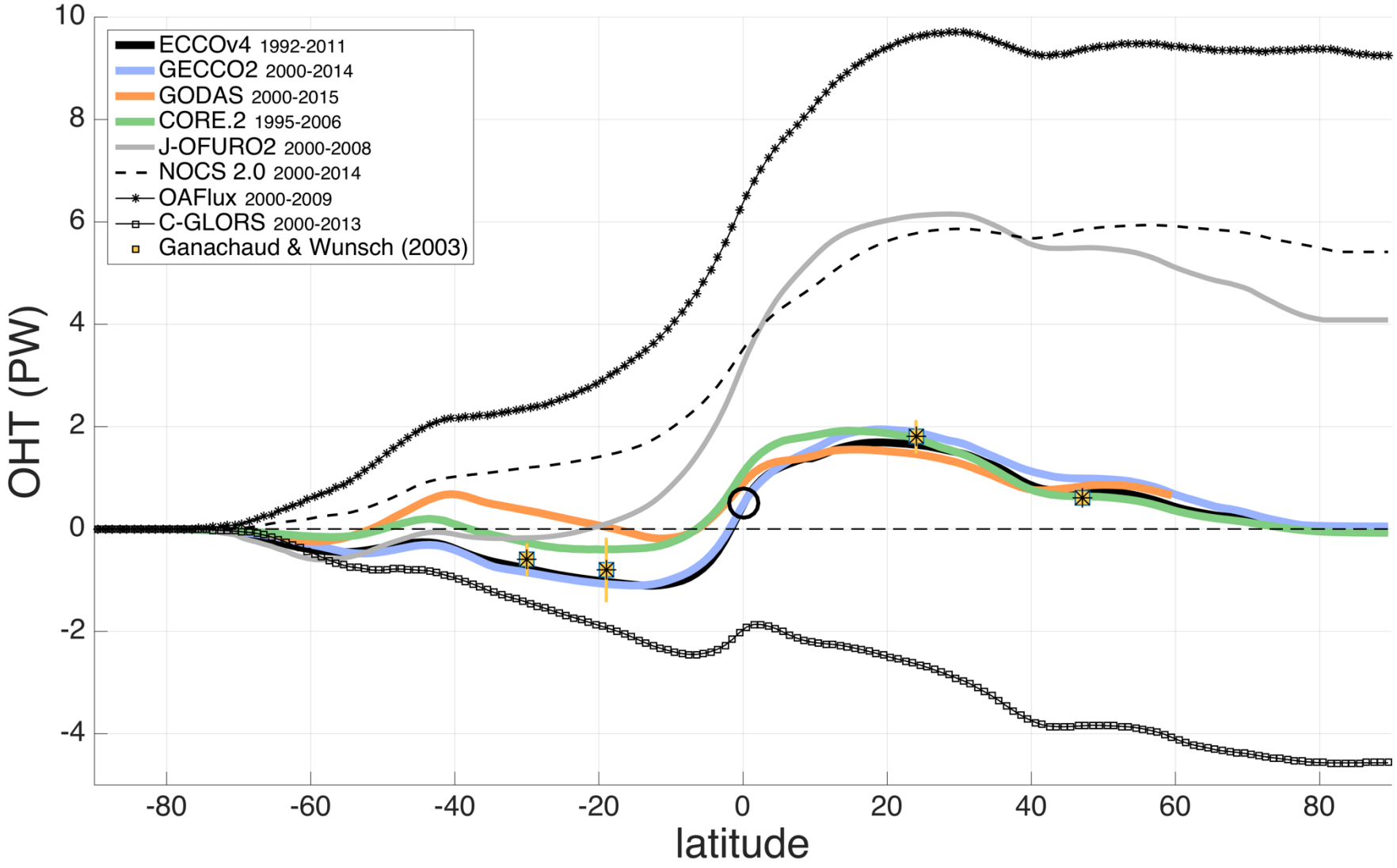
  - Global Ocean Data Assimilation System Global Ocean Physics Reanalysis **C- GLORS**

  - NCEP Global Ocean Data Assimilation System **GODAS**

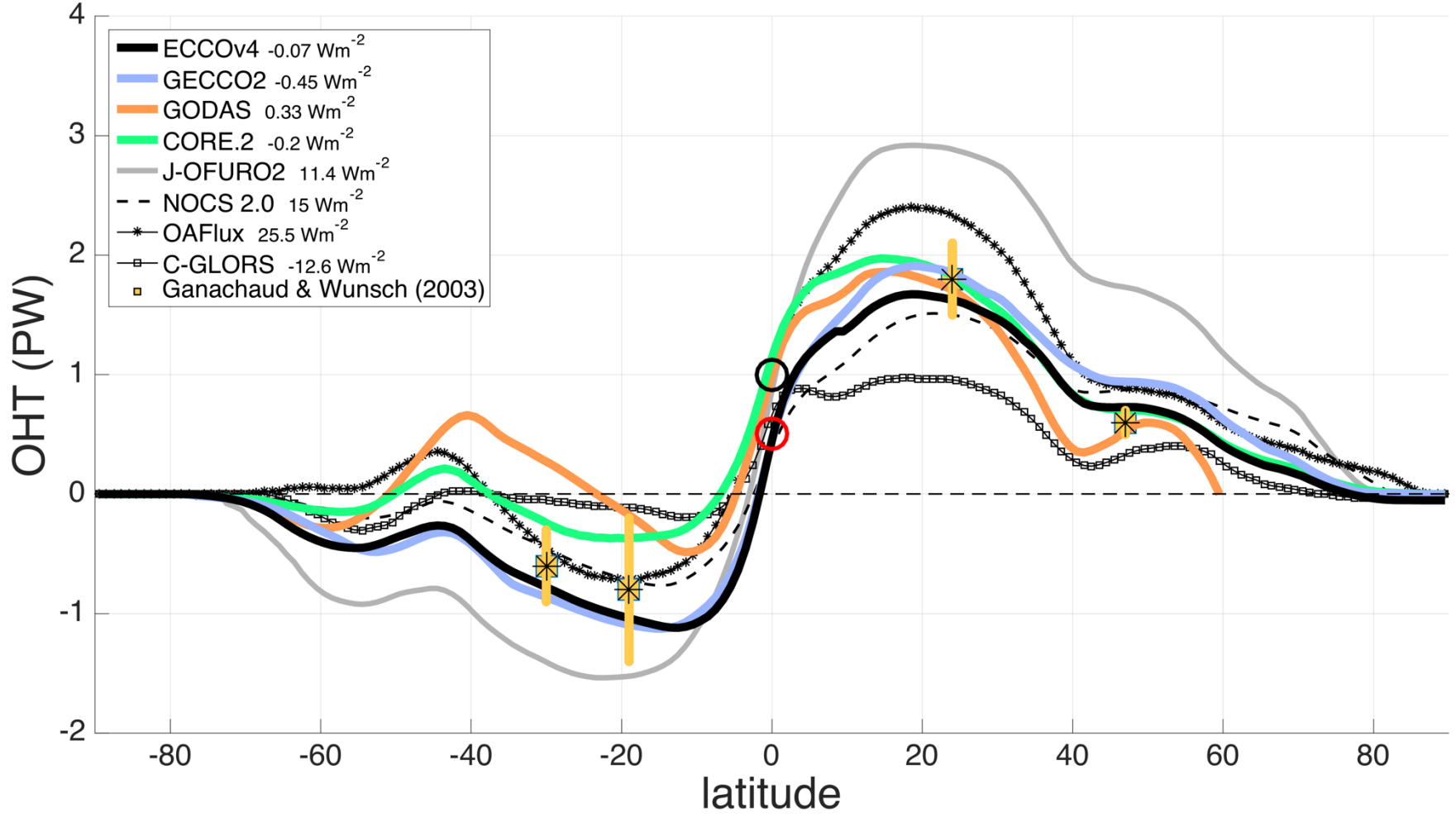
- **hybrid products** (atmospheric reanalysis + satellite):
  CORE.2 Global Air-Sea Flux, **OAFlux** Objectively Analyzed air-sea Fluxes

- **satellite and ship** products: J-OFURO2, NOCS Surface Flux Dataset

OHT = zonally integrated F_s (PW)



Balanced ocean heat transport



Best estimate cross-equatorial OHT: 0.4-0.6 PW

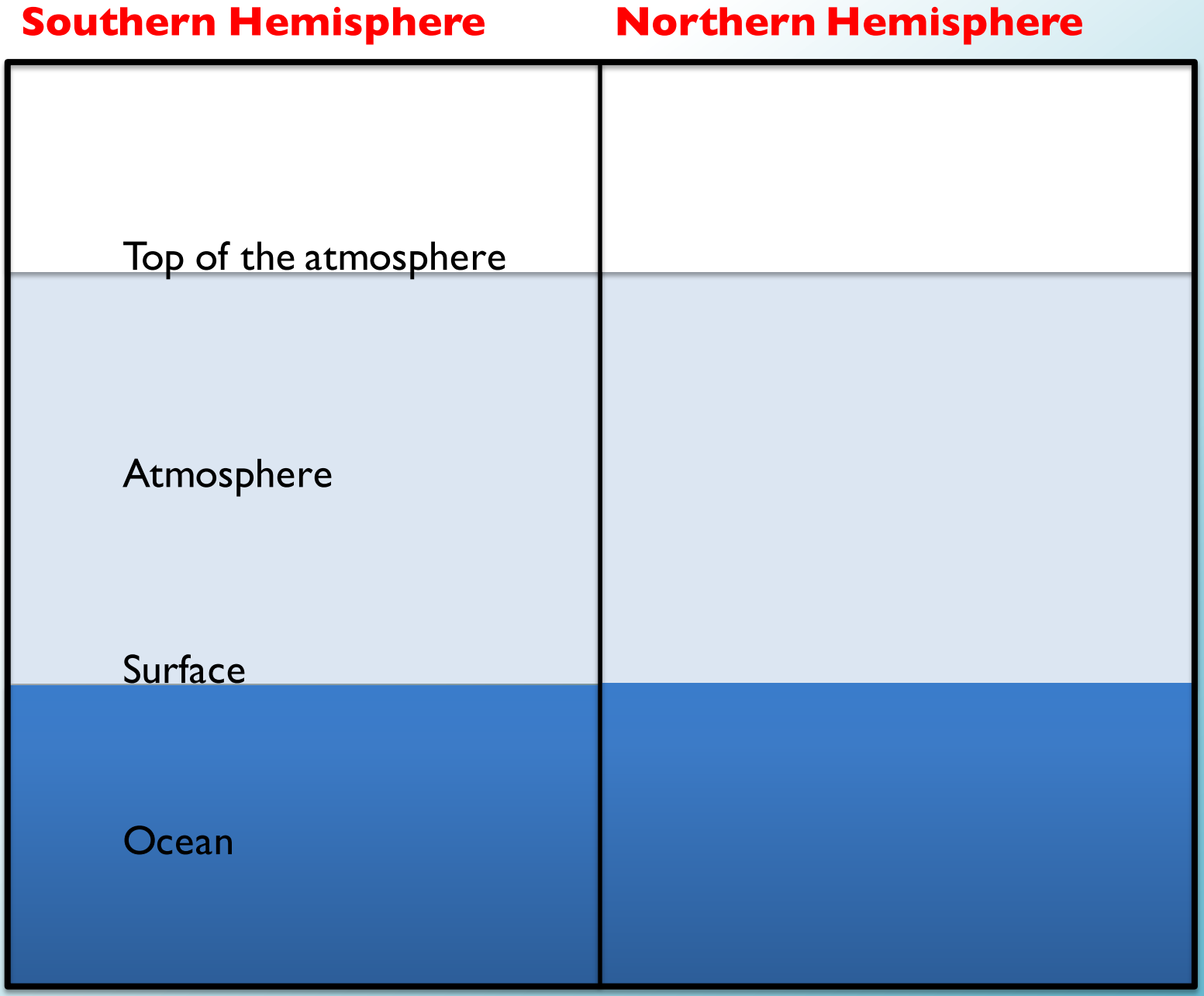
"in-situ" measurements from hydrographic inverse box models, where relative, geostrophic velocity field is obtained from temperature and salinity measurements across oceanic sections

Oct 19 – M.Z. Hakuba

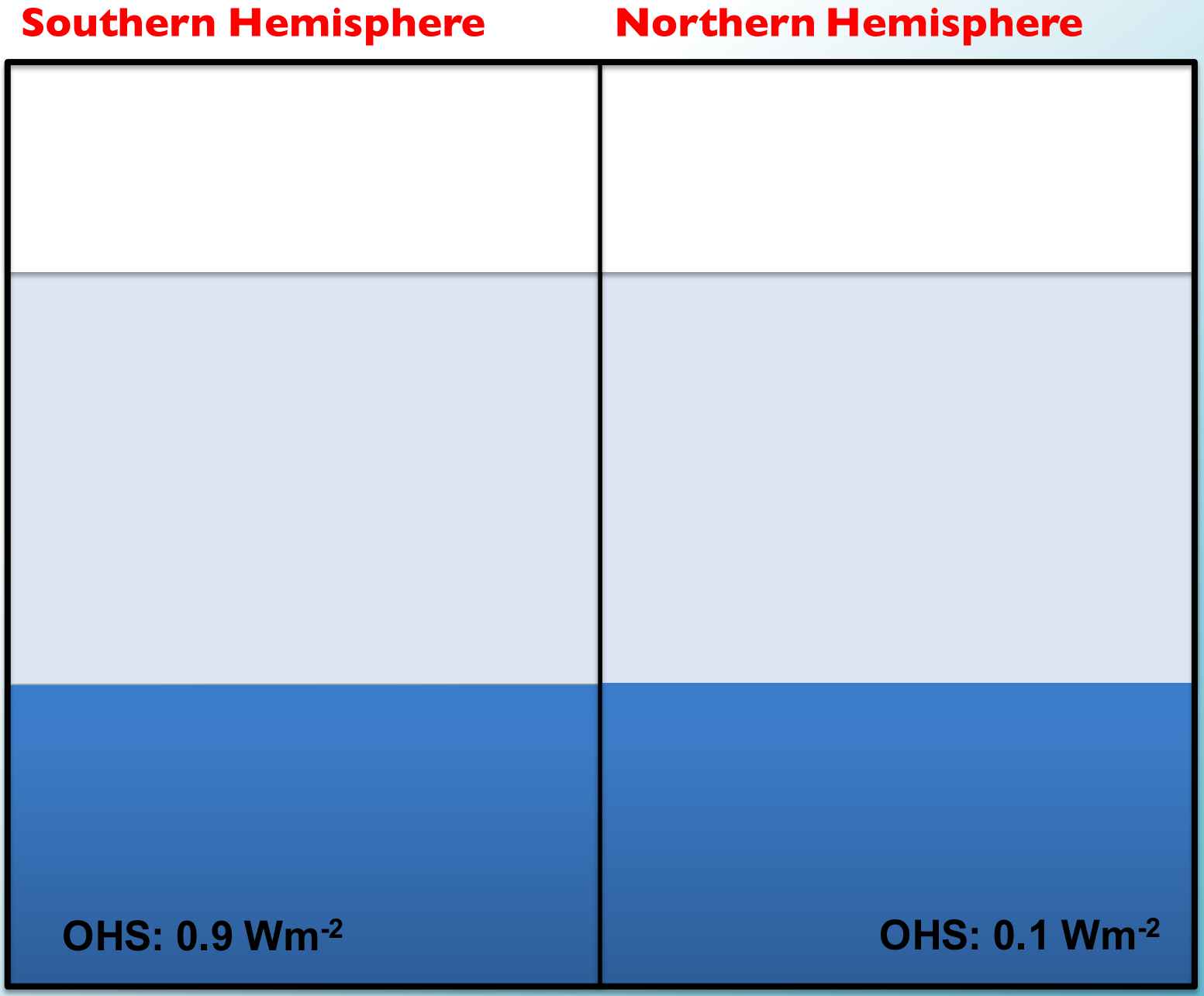
Challenges with OHT

- Indirect method is circular: Do we integrate OHS?
- Is COHT systematically overestimated?
- Get "real" OHT from models and reanalysis
- Or find way to account for OHS in F_s datasets (Subtract OHS per latitude?)
- Given the range of estimates and large uncertainty, truth could be in there. Certainly OHT is northward

Hemispheric energy balance



Hemispheric energy balance



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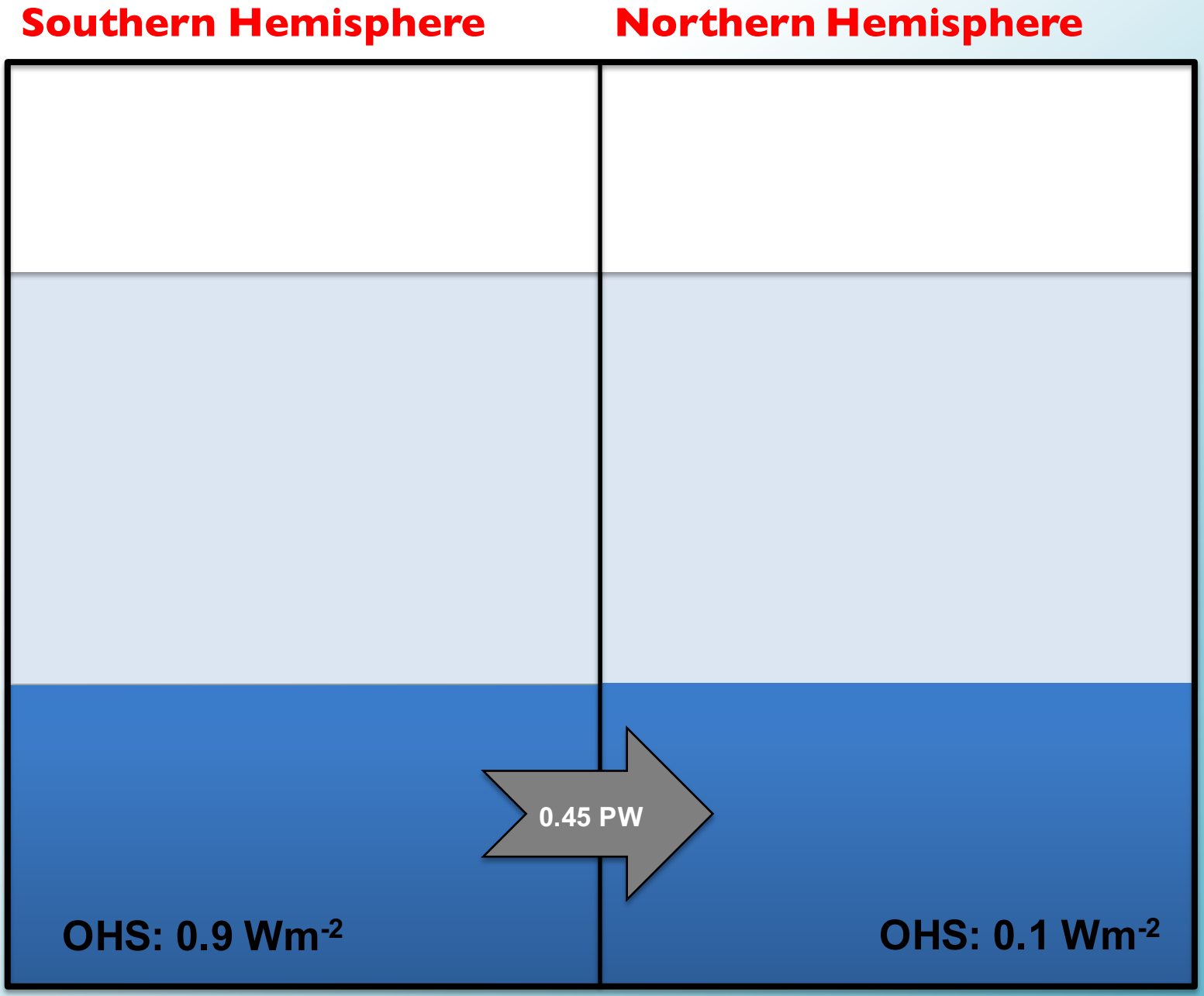

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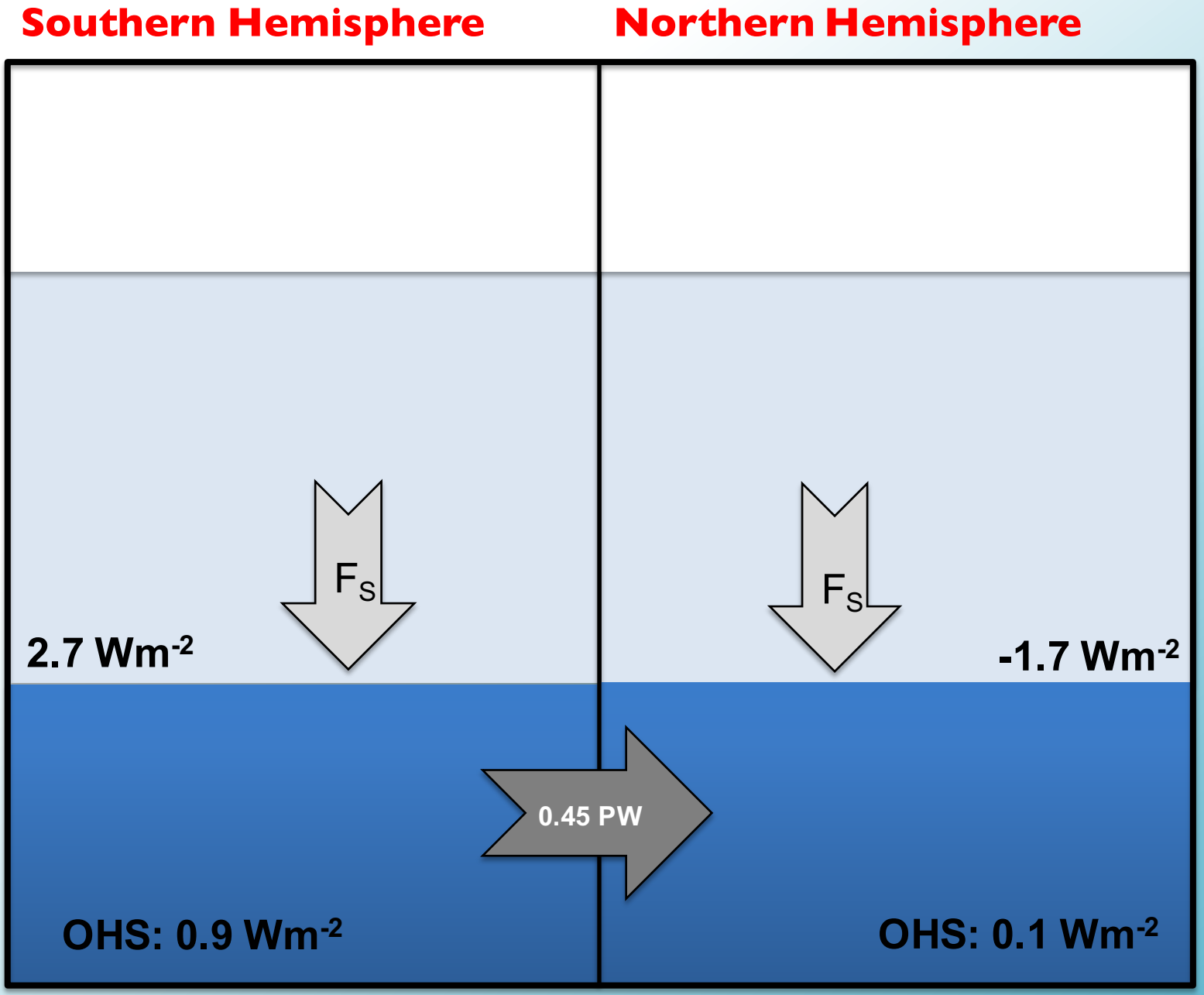

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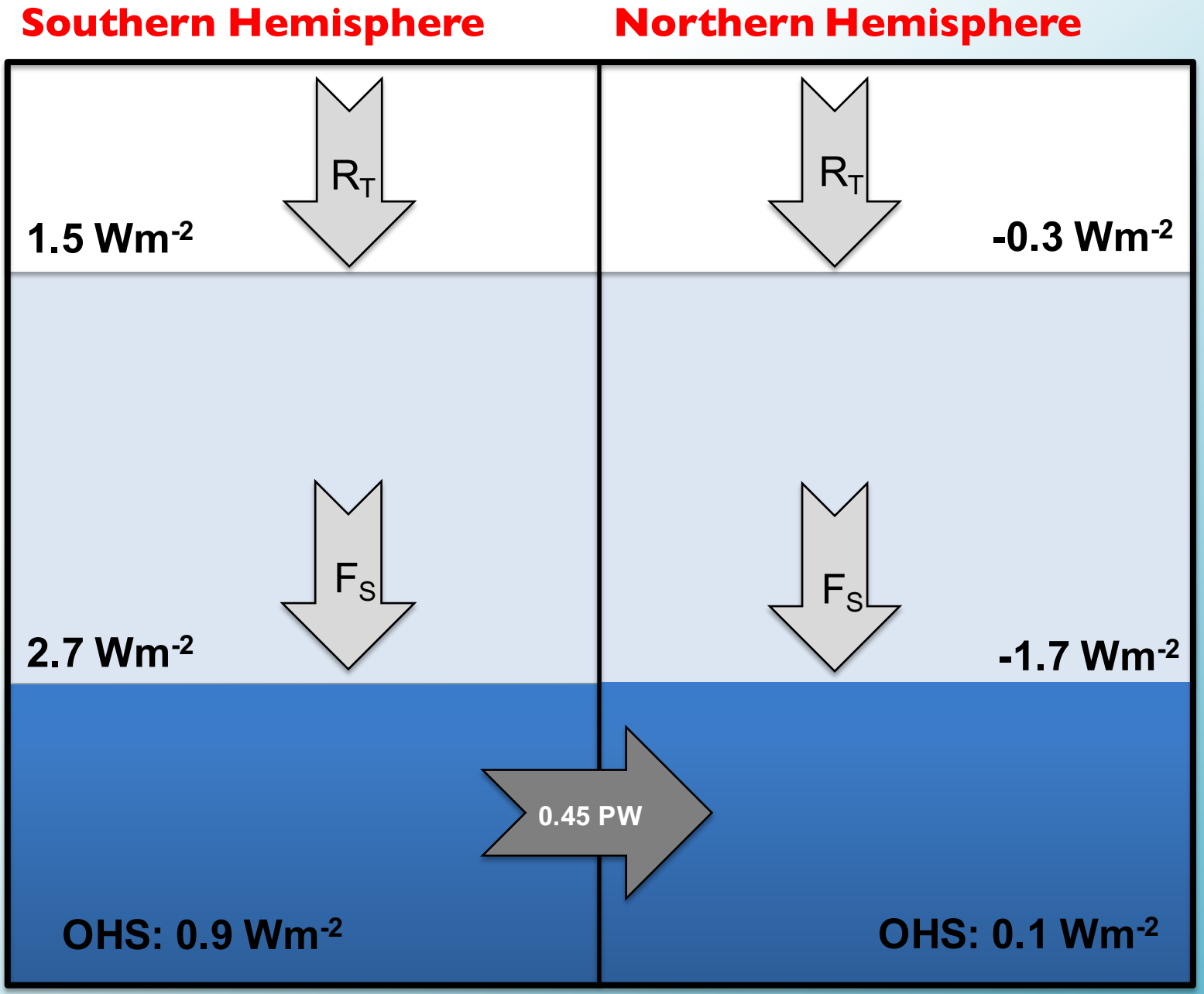

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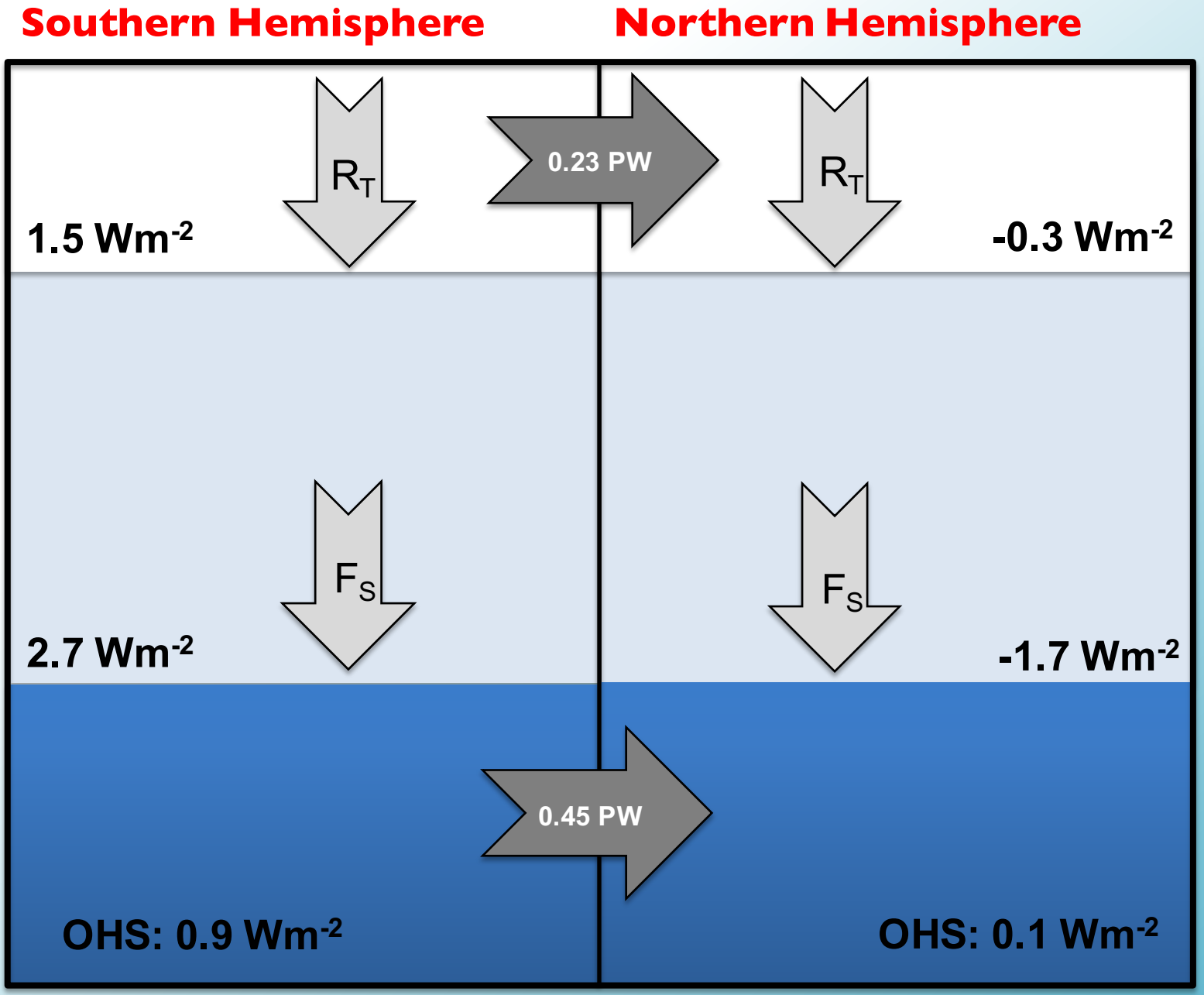
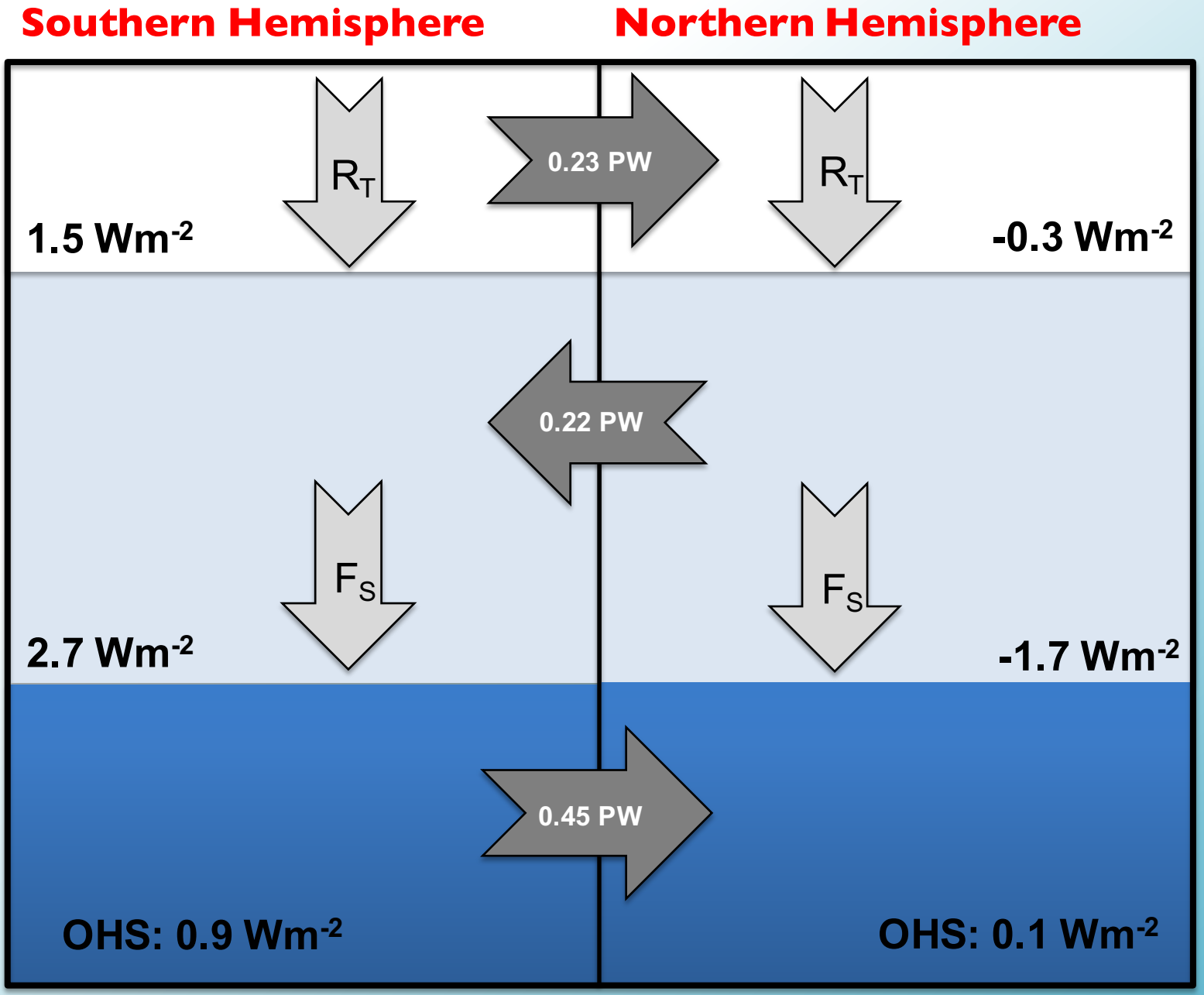


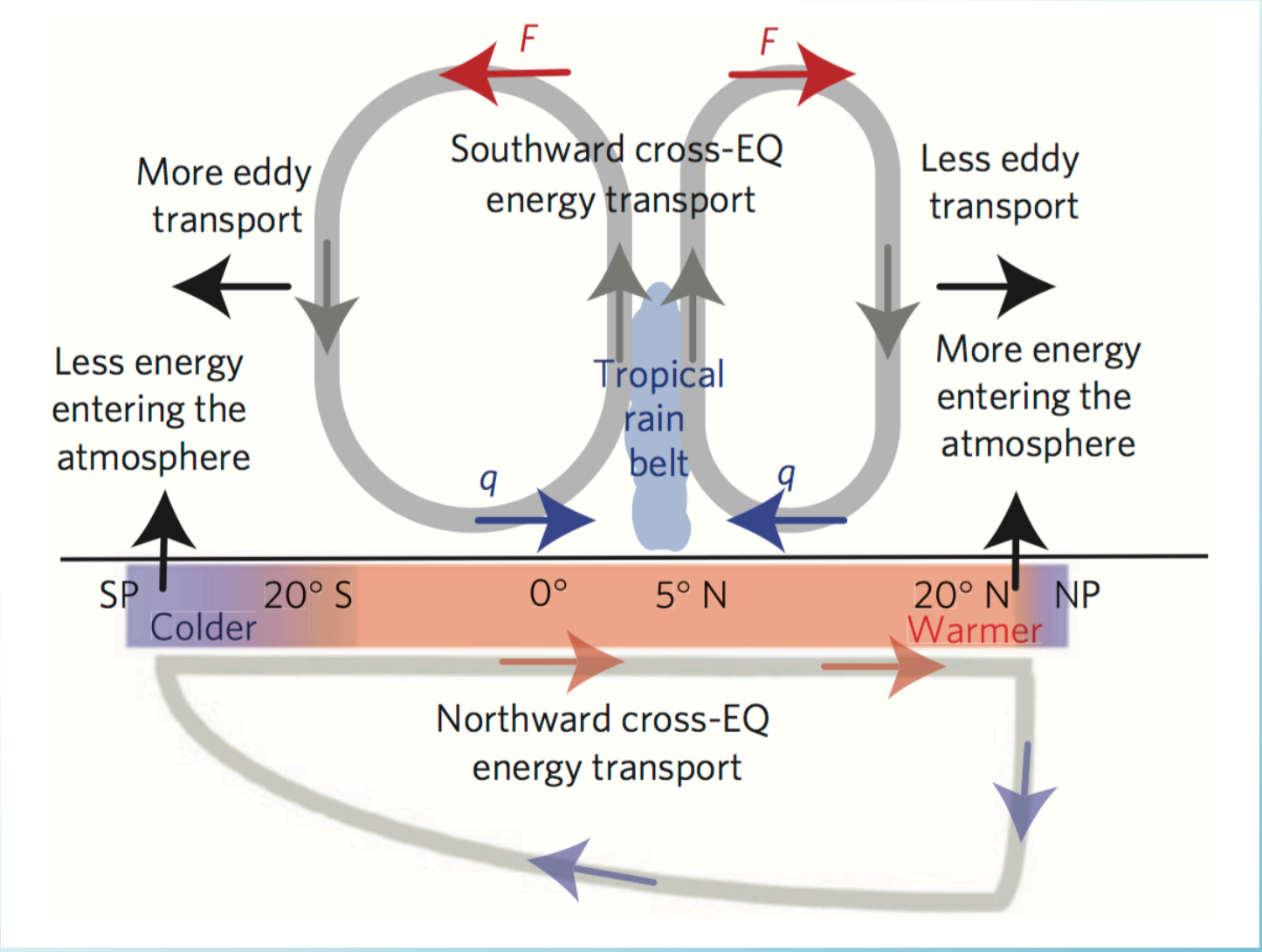
Hemispheric energy balance



Atmospheric dynamics

Tropical circulation governs atmospheric energy transport

Intertropical convergence zone



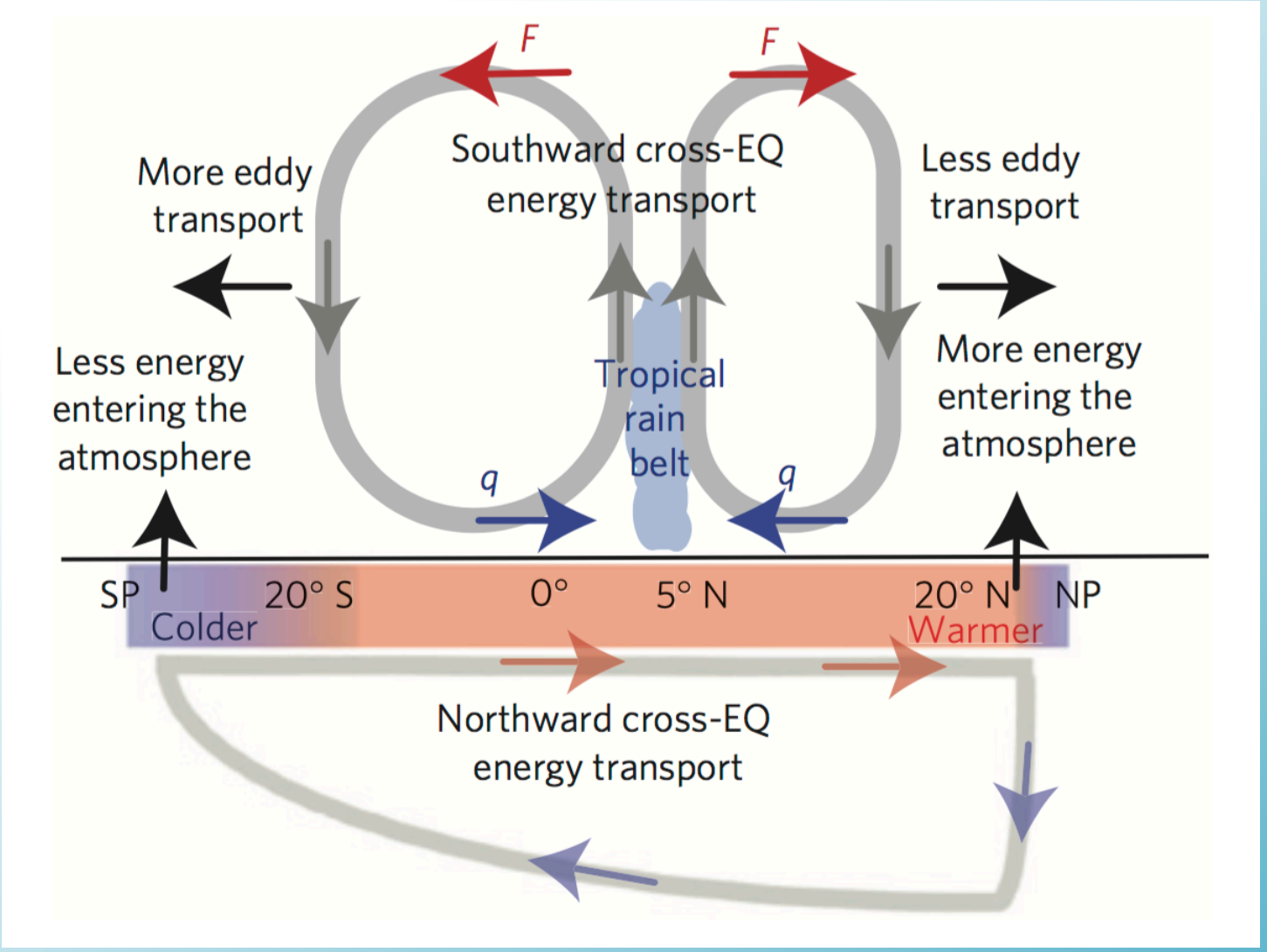
Frierson et al. (2013), Nature Geo.

Schneider et al., 2014

Hadley circulation governs atmospheric energy transport

Intertropical convergence zone

- **Energetics drive location of ITCZ and peak in precipitation!**



Intertropical convergence zone

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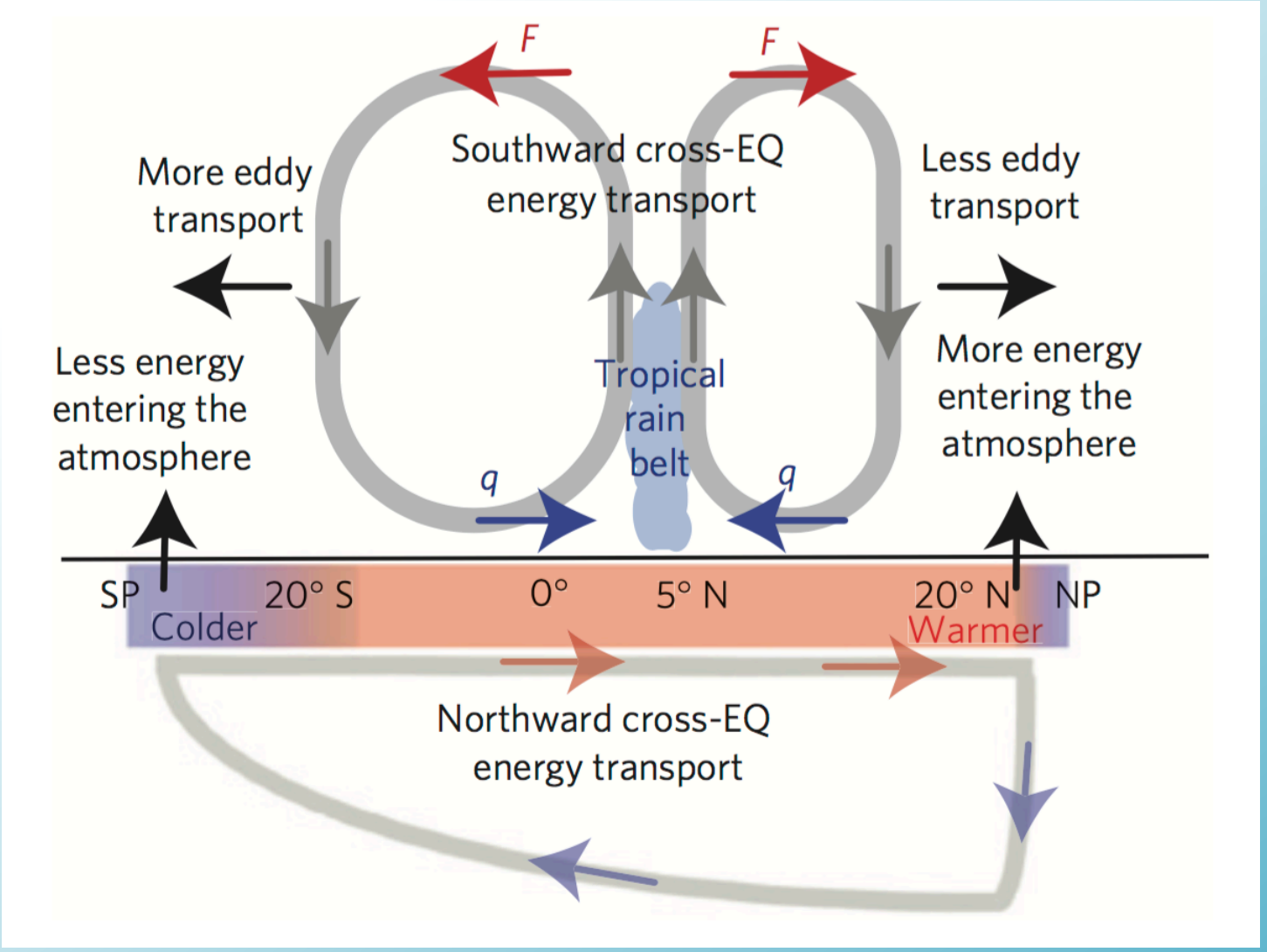
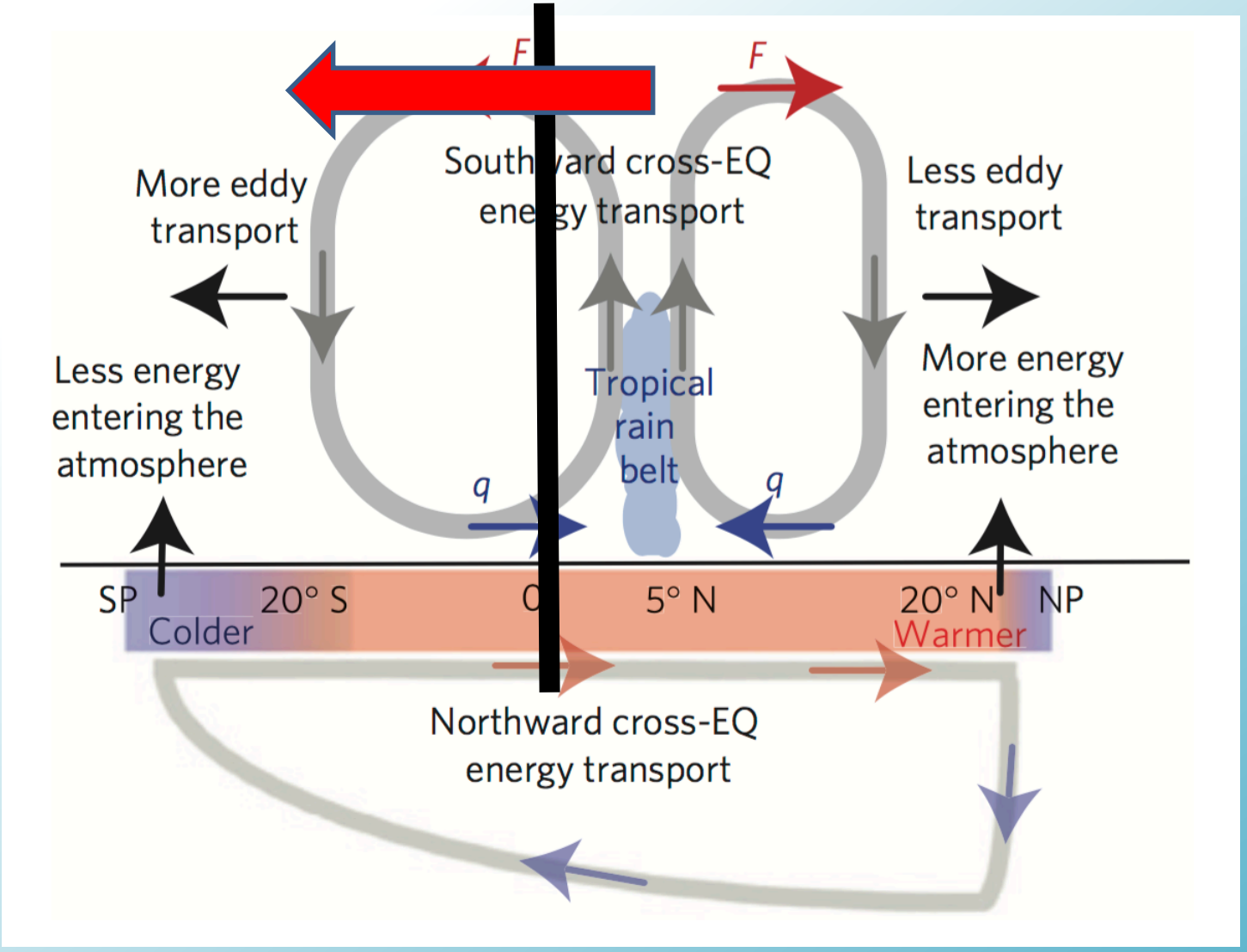


In the NH, heat is released from the ocean to the atmosphere owing to cross-equatorial OHT.

Intertropical convergence zone

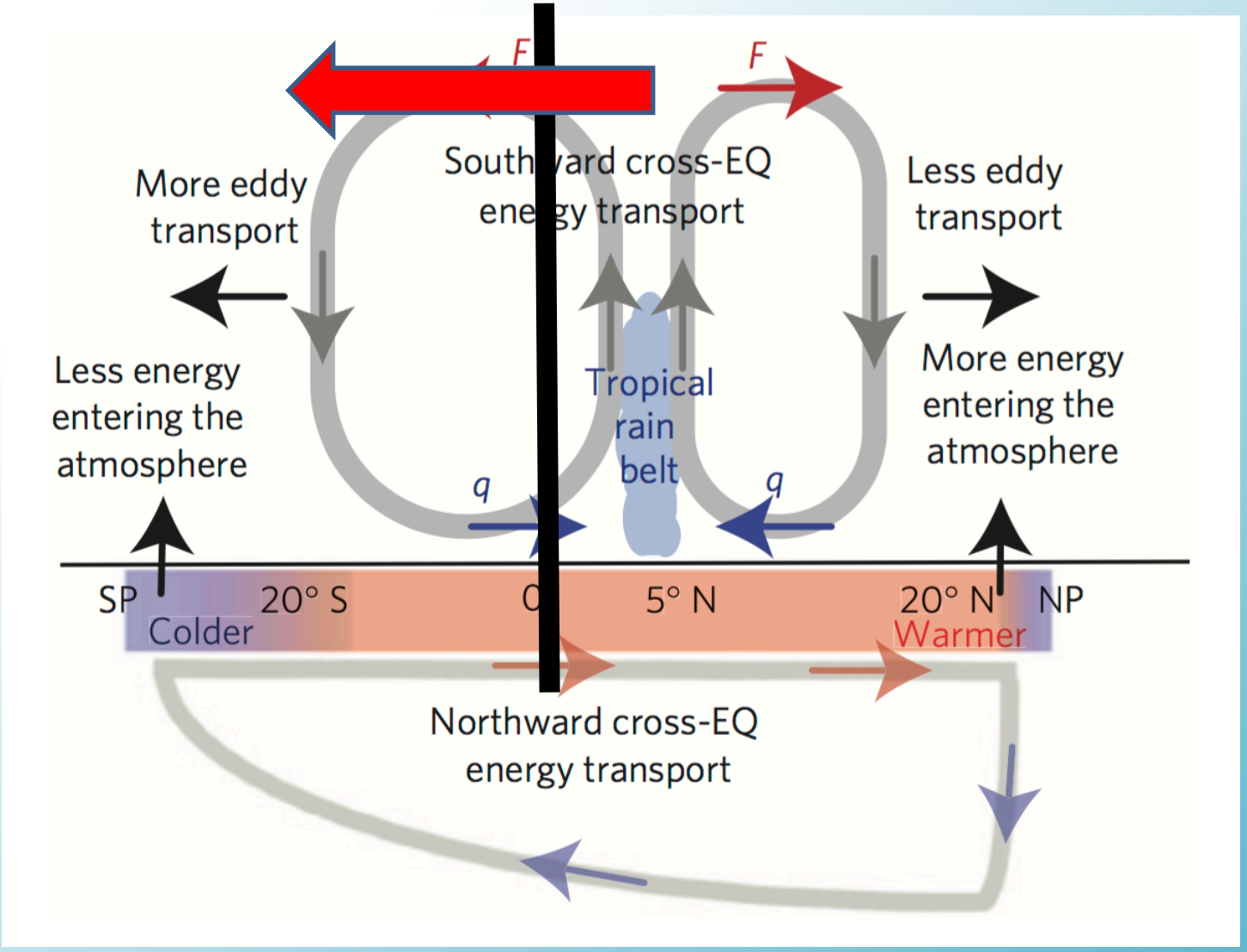
- **Energetics drive location of ITCZ and peak in precipitation!**



displaced Hadley circulation that fluxes energy from the NH to the SH = cross-equatorial atm. heat transport

Intertropical convergence zone

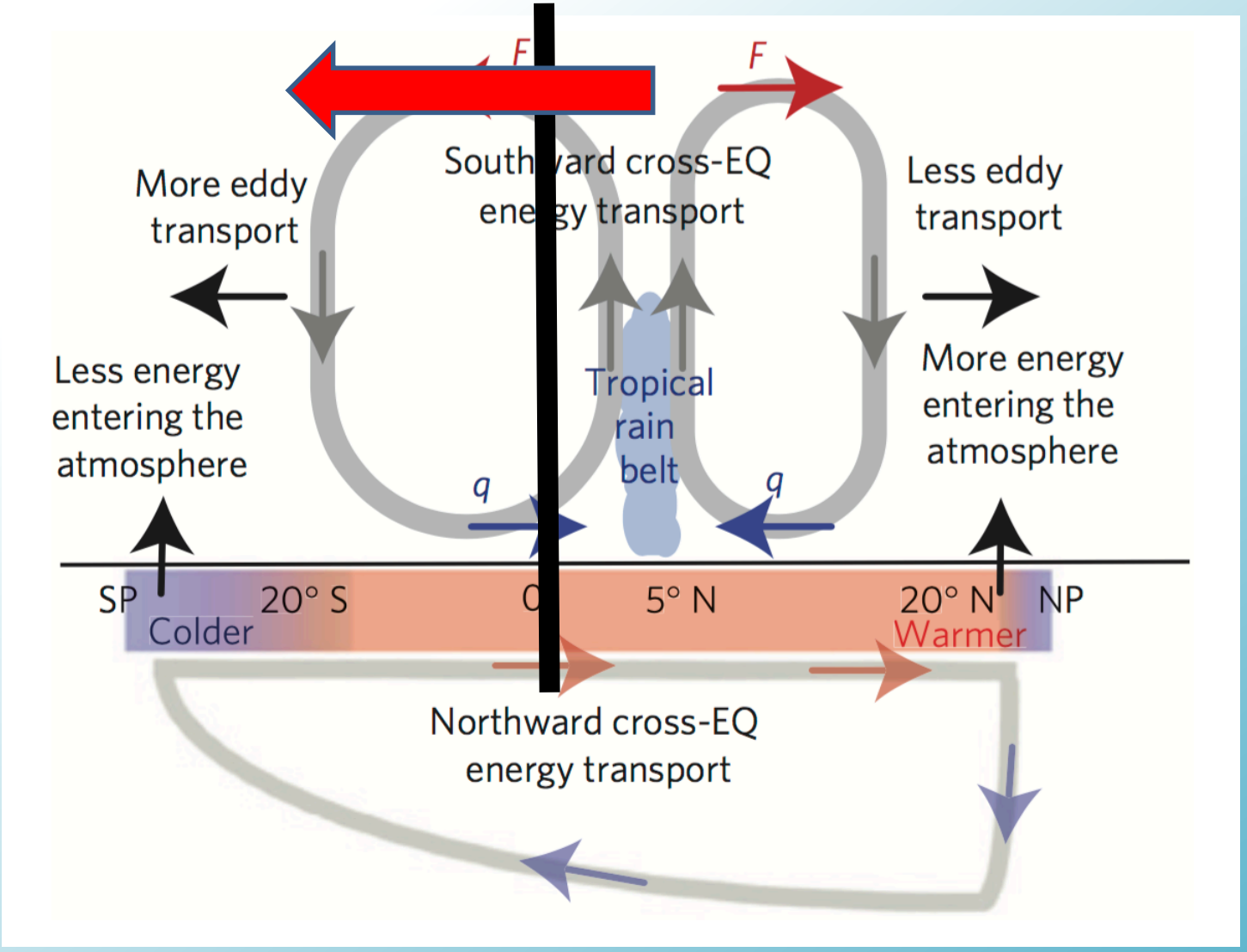
- **Energetics drive location of ITCZ and peak in precipitation!**
- **What if energetics change?**



displaced Hadley circulation that fluxes energy from the NH to the SH = cross-equatorial atm. heat transport

Intertropical convergence zone

- **Energetics drive location of ITCZ and peak in precipitation!**
- **What if energetics change?**
- **15K years ago, ITCZ resided in SH!** McGee et al., 2014



→ **displaced Hadley circulation that fluxes energy from the NH to the SH = cross-equatorial atm. heat transport**

Conclusions & Outlook

Northward ocean heat transport: 0.45 PW

Ocean heat storage: 0.1 Wm^{-2}

Ocean heat storage: 0.9 Wm^{-2}

Challenges in energy balance studies

- Large uncertainties in surface energy balance
  - Use of ocean heat data to better constrain
- Regionalization: separation into hemispheres
  - Inter-hemispheric heat transports

NEXT: - Role of tropical circulation:
What sets the location of ITCZ?
- Improved estimates of ocean heat transport and heat storage

Conclusions & Outlook

Beyond further exploration of different datasets, methods, and study of dynamics:

Advance and ensure the continuous monitoring of the **Radiation** and **ocean** heat budget

= ultimate proxies for climate change

Conclusions & Outlook

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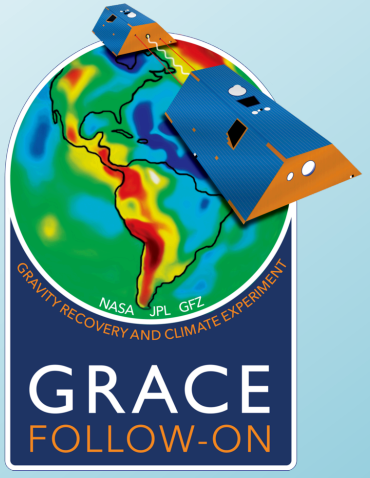
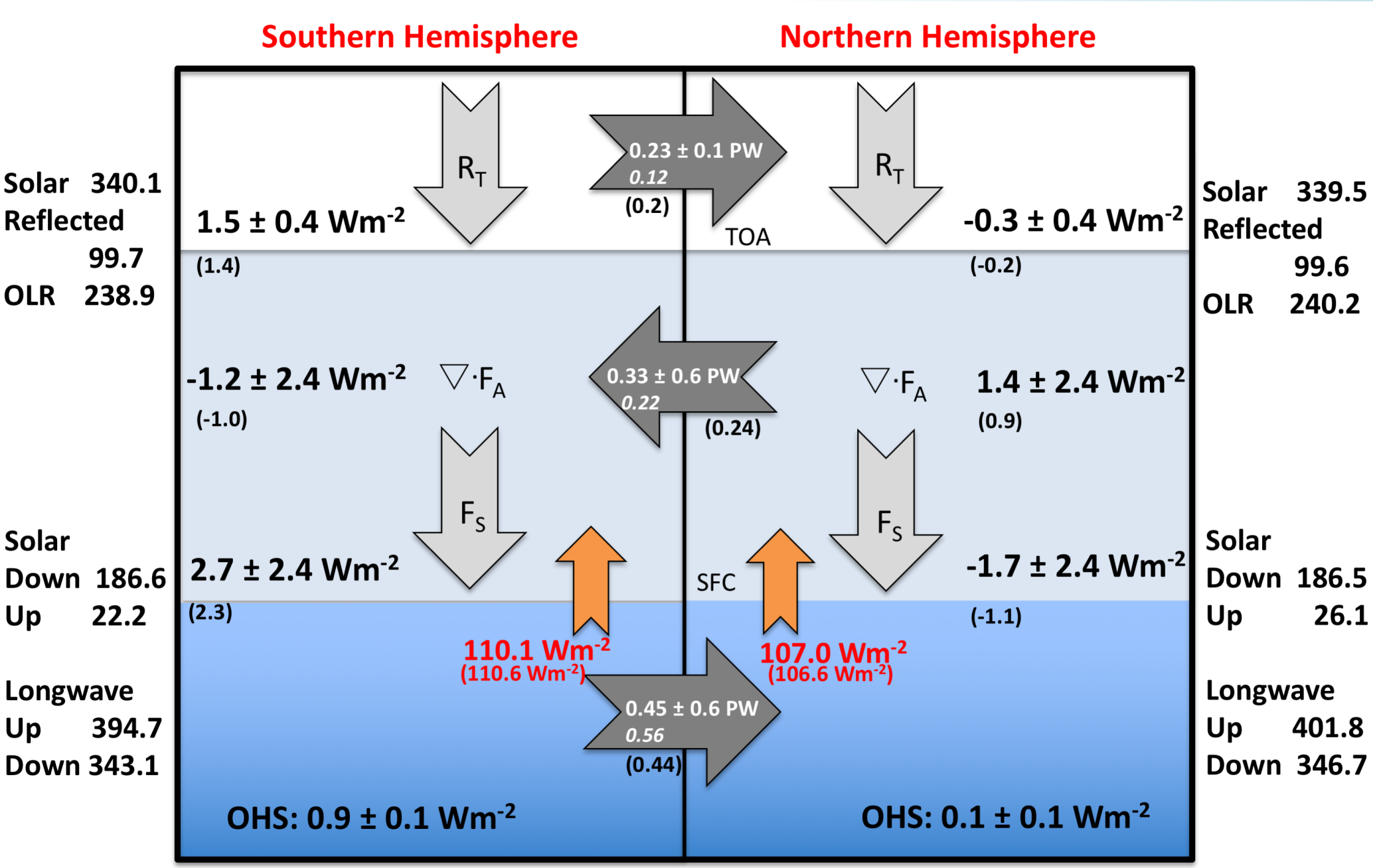
Advance and ensure the continuous monitoring of the **Radiation** and **ocean** heat budget

= ultimate proxies for climate change

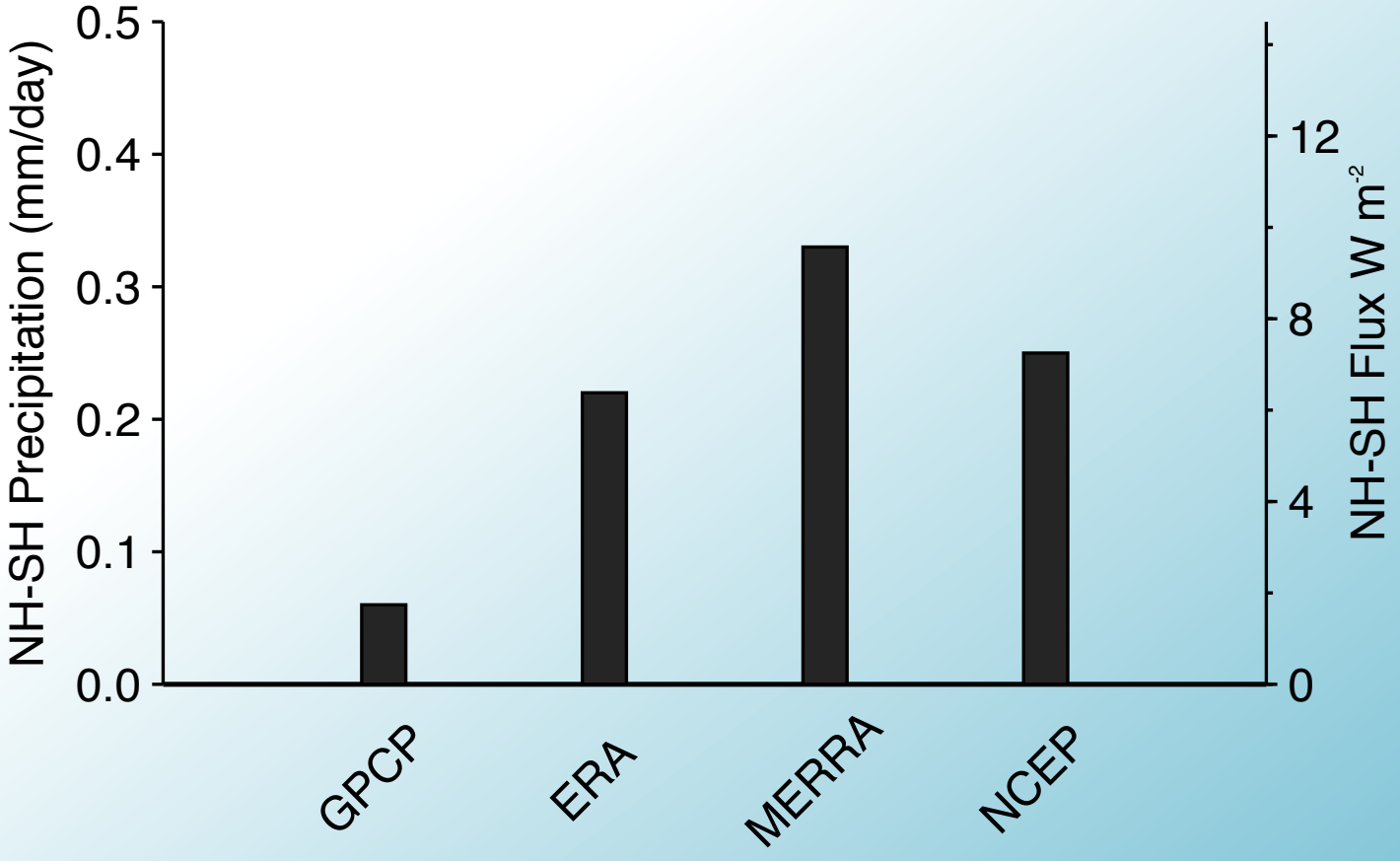


Thank you!

Hemispheric energy balance

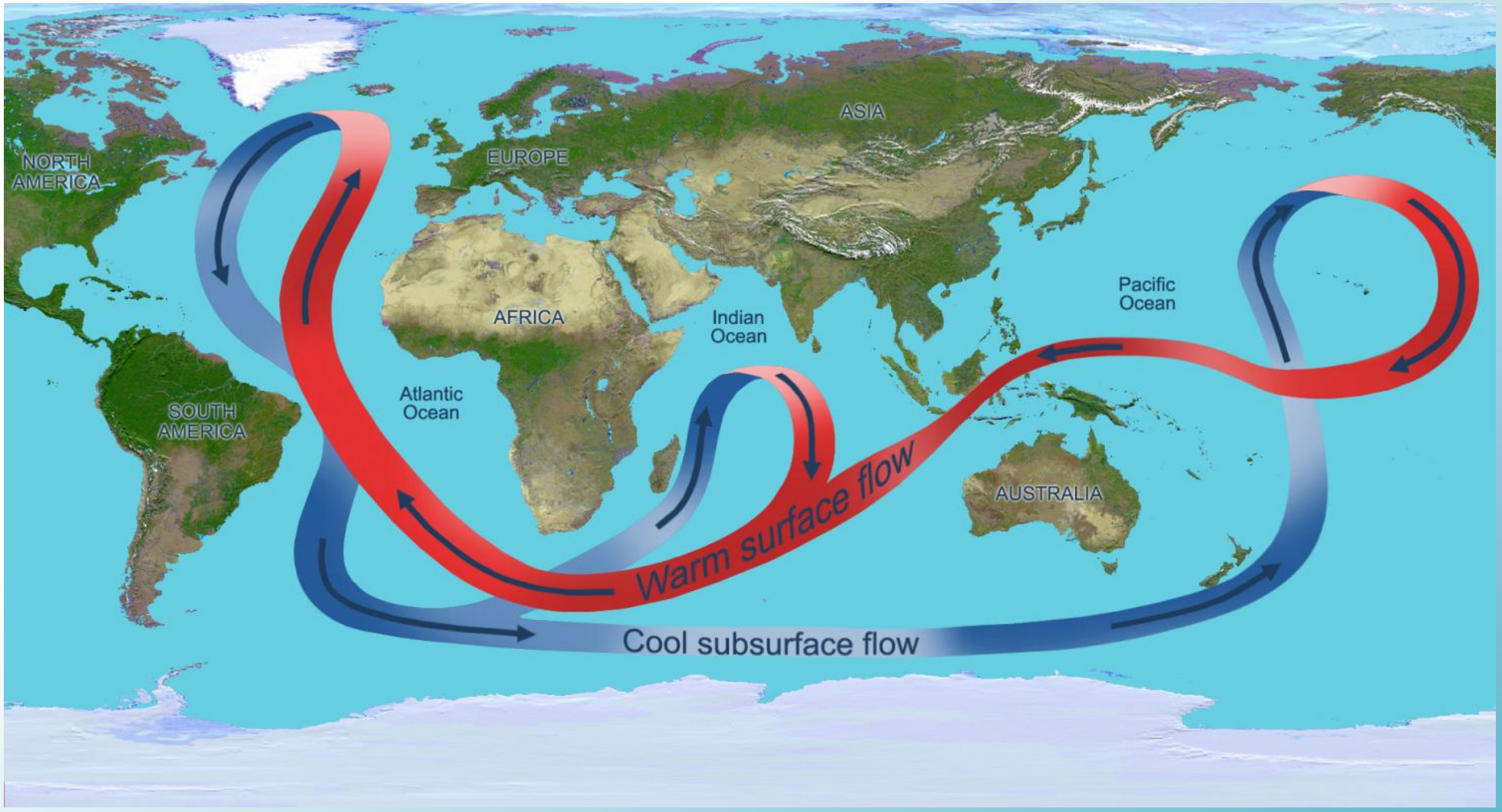


Indeed: slight precip. asymmetry …

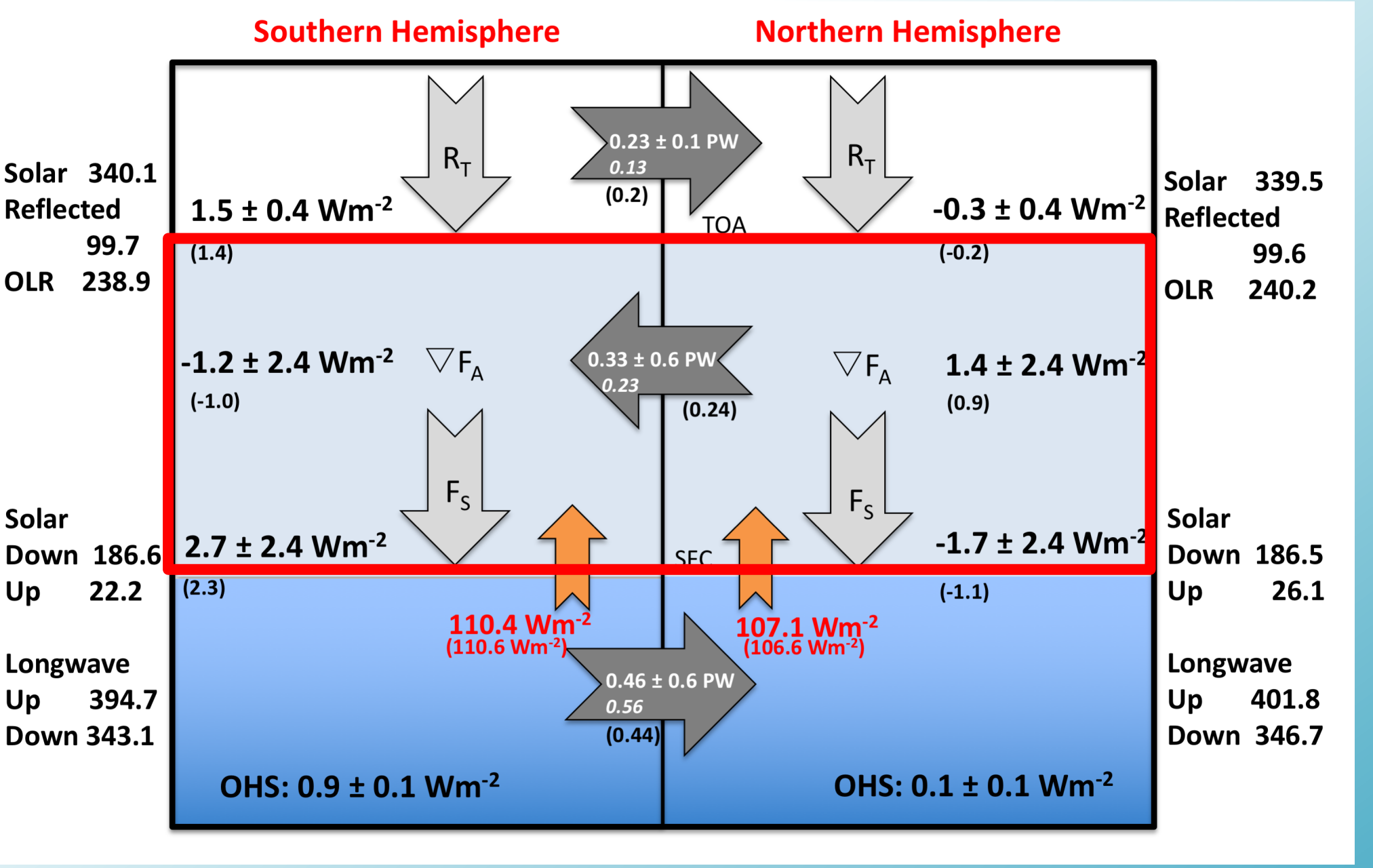


GPCP: 0.6 mm/day more precip. in NH = 2 Wm^{-2} (energy equivalent).
Interesting: CloudSat data show : precip is more intense in NH, but more frequent in SH!

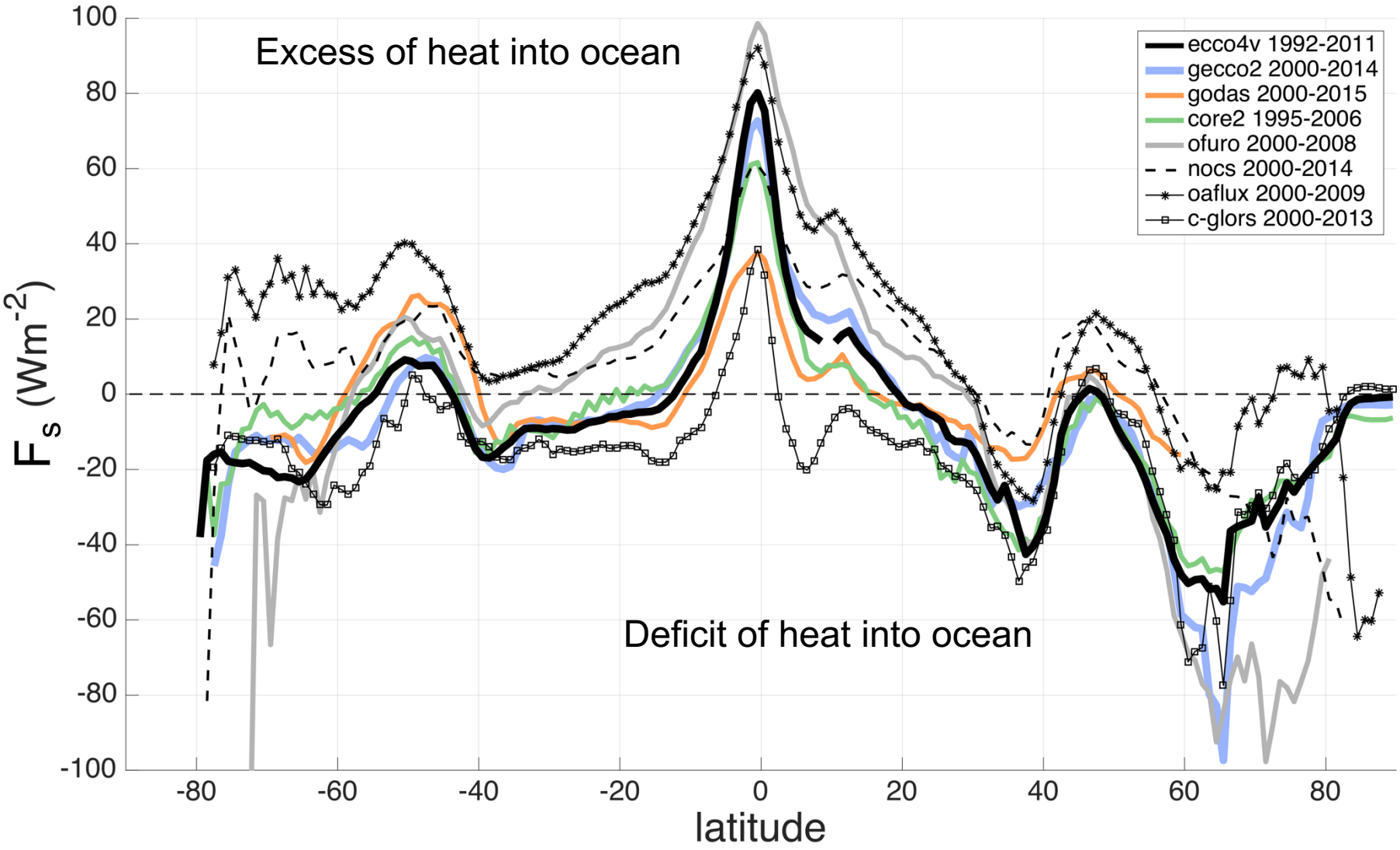
Ocean overturning circulation



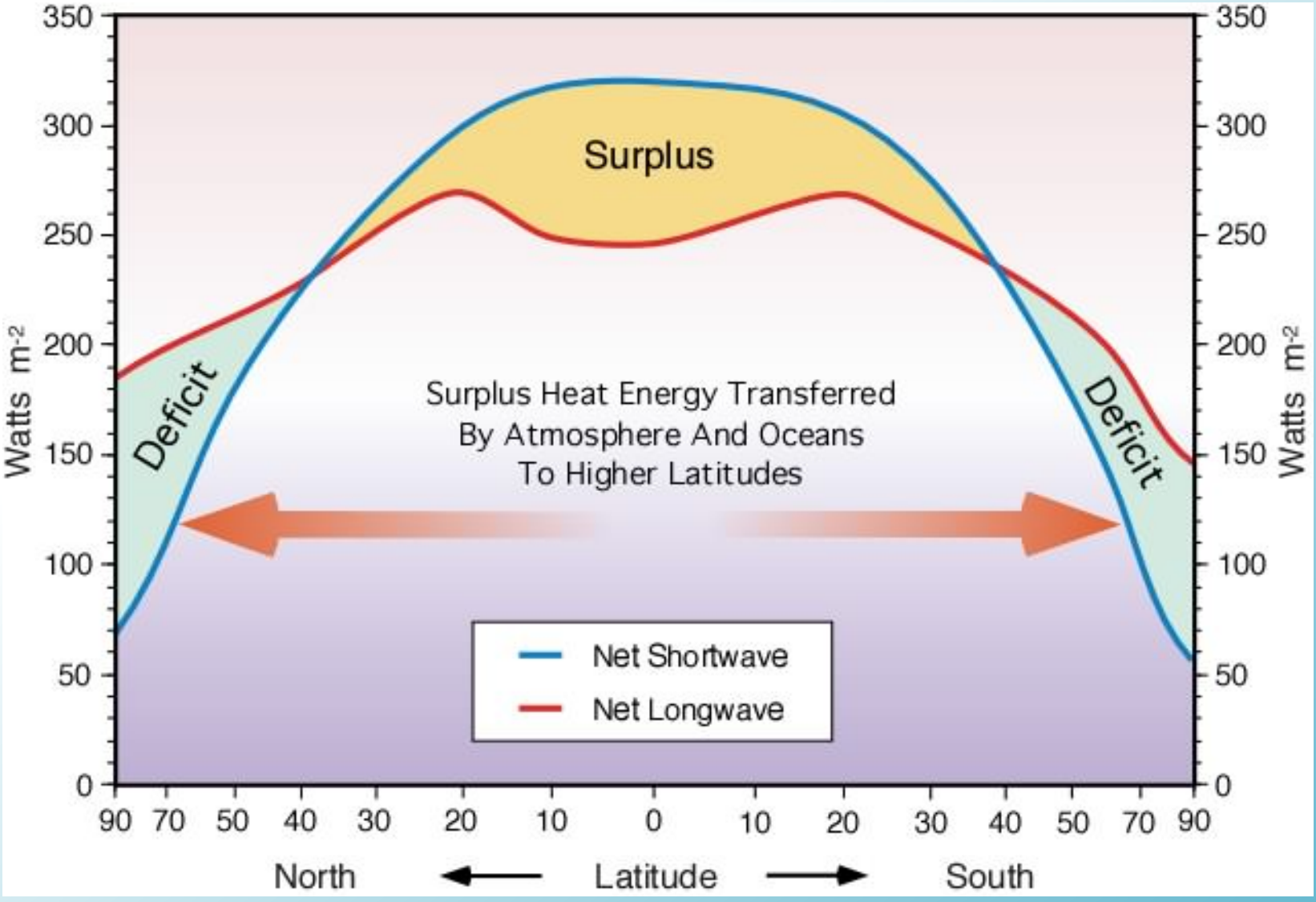
Hemispheric energy balance

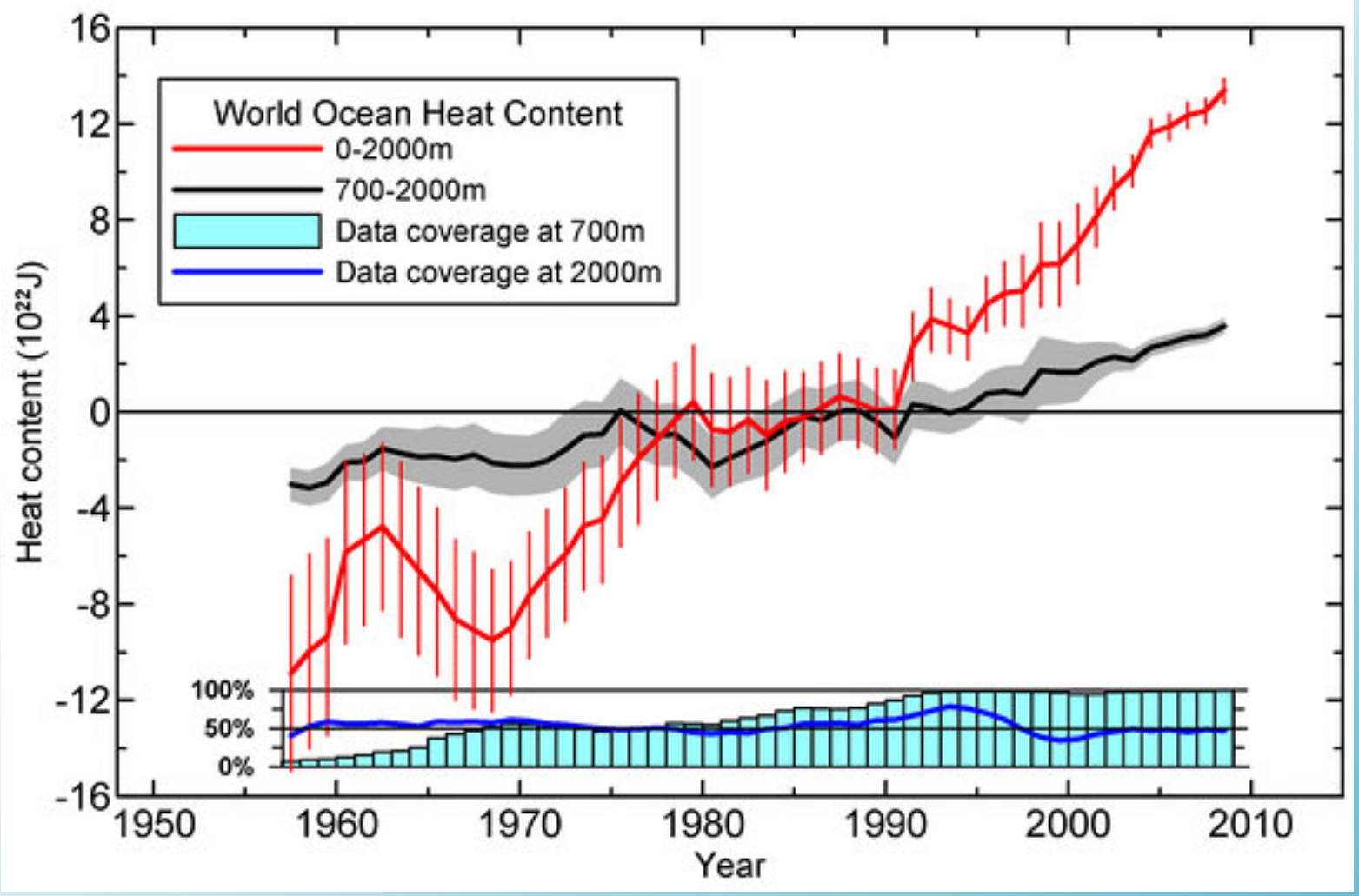


Surface net heat flux



Speaking of transport




World Ocean Heat Content
0-2000m
700-2000m
Data coverage at 700m
Data coverage at 2000m
Heat content (10^{22}J)
16
12
8
4
0
-4
-8
-12
-16
100%
50%
0%
1950
1960
1970
1980
1990
2000
2010
Year

Conclusions & Outlook

Advance and ensure the continuous monitoring of the Radiation and **ocean** heat budget and heat transport

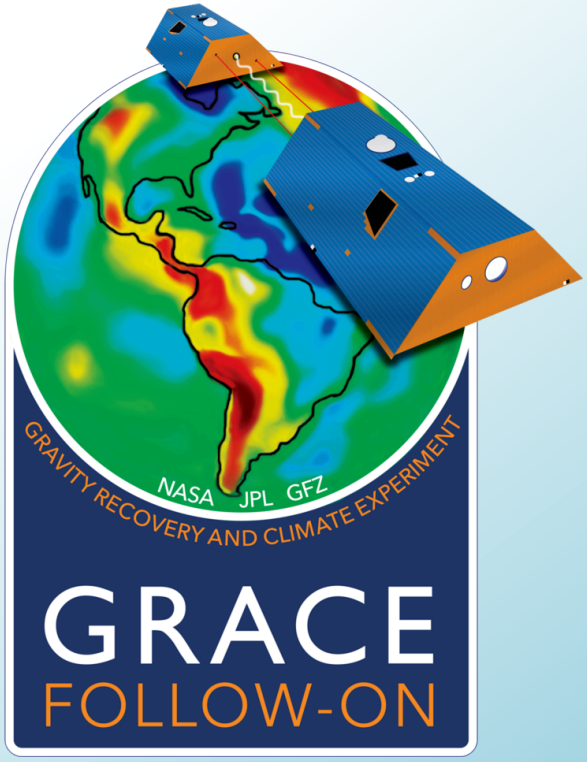


Figure 1: Time series for the World Ocean of ocean heat content (1022 J) for the 0-2000 m (red) and 700-2000 m (black) layers based on running pentadal (five-year) analyses. Reference period is 1955-2006. Each pentadal estimate is plotted at the midpoint of the 5-year period. The vertical bars represent ±2.S.E. about the pentadal estimate for the 0-2000 m estimates and the grey-shaded area represent ±2.S.E. about the pentadal estimate for the 0-700 m estimates. The blue bar chart at the bottom represents the percentage of one-degree squares (globally) that have at least four pentadal one-degree square anomaly values used in their computation at 700 m depth. Blue line is the same as for the bar chart but for 2000 m depth.
Levitus et al, 2012

e use the term
ocean heat content
as opposed to
ocean heat content anomaly
used by some authors because
ocean heat content
is an anomaly by definition. OHC is
always computed with a reference mean subtracted
out from
each temperature observation. Otherwise the OHC
compu-
tation depends on the temperature scale used.